DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

BEACH EROSION BOARD

OFFICE OF THE CHIEF OF ENGINEERS

LABORATORY STUDY OF THE GENERATION OF WIND WAVES IN SHALLOW WATER

TECHNICAL MEMORANDUM NO. 72

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FOREWORD

The prediction of wave characteristics in shallow water is of great importance along much of the Gulf Coast of the United States, as well as for many inland water areas (as Lake Okeechobee, Florida). This has been difficult in the past as the effect of the shallow bottom is considerable, particularly in reducing the wave height from what would be expected by use of the deep water wave prediction methods. This report gives the results of some laboratory studies of wave generation in shallow water in a small enclosed wind-wave tank.

This report was prepared at the University of California in Berkeley in pursuance of contract DA-49-055-eng-31 with the Beach Erosion Board which provides in part for research and investigation on wave generation in shallow water. The author, Osvald Sibul, is a Research Engineer at that institution working primarily in the Wave Research Laboratory.

The work done on this study was supported jointly by the Jacksonville District, Corps of Engineers, and the Beach Erosion Board. The funds were allotted from the Civil Works Investigation Program of the Office, Chief of Engineers under projects CW 166 and CW 167, "Study of Waves and Wind Tides in Shallow Water".

Views and conclusions stated in this report are not necessarily those of the Beach Erosion Board.

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LABORATORY STUDY OF THE GENERATION OF WIND WAVES IN SHALLOW WATER

by
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ABSTRACT

Wind waves in shallow water were studied in a laboratory channel. The experiments were conducted with smooth and rough bottom conditions, and with strips of cheese cloth in the channel to simulate the roughness effects of vegetation in nature. The data indicate that the Sverdrup-Munk-Bretschneider curves may be used to predict the wave heights and periods for relatively deep water. In shallow water the wave heights may be considerably lower than predicted by the curves, depending upon the relative depth of water. The experiments indicate that the depth starts to affect the wave heights at approximately $d/H_o < 5$. The wave periods are also affected by the depth, but not as much as are the wave heights. The reduction in period can be noticed when $d/L_o < 0.2$; the period continues to decrease with decreasing depth. Further, it was found that the maximum wave height for a group of 100 waves is 1.34 times that of the significant wave height and 1.93 times that of mean wave height, H_{mean}. The average period of the significant waves ($T_{H1/3}$) and the maximum waves ($T_{H\ max}$) was found to be of the same magnitude and equal to 1.10 times the mean wave period T_{mean}. The maximum wave period almost never coincided with the maximum wave height. The maximum wave period T_{max} was found to be 1.25 times that of significant wave period $T_{1/3}$, and 1.42 times that of mean wave period, T_{mean}.

INTRODUCTION

When the wind is blowing over the water surface it generates waves, the heights and periods of which are a function of wind intensity and duration, fetch, and water depth. The characteristics of the ocean or of lake surfaces are of interest to those concerned with the problems of coastal engineering or shipping. Some of these problems are: design of harbors and shore protection works such as levees, dams, and breakwaters; loading and unloading of ships; and the operation of seaplanes. During the past half century, data on wind waves have been taken by several observers and under a great variety of conditions. Many of these data were obtained from visual observations with the wind speeds being estimated either from scattered observations or from weather maps. Sverdrup and Munk(1)* developed in the early "40's" (published 1947) a semi-empirical theory relating the wave heights, periods, and steepnesses to the intensity and duration of the wind and the length of the fetch.

*Numbers in parentheses refer to references on pages 34 and 35.

In their treatment several numerical coefficients were obtained from observations of wind and waves at sea. The data were insufficient to check the theory for a wide range of conditions. Since these results were published, many new data have been made available. These include laboratory investigations by Flinsch[2] and Johnson and Rice[3] in the United States; and Francis[4] in England. Field measurements have been made by Johnson (5,6) on relatively small bodies of water with limited fetches at both Clear Lake, California and Abbotts Lagoon, California. The new data, as well as the original data of Sverdrup and Munk were analyzed by Bretschneider[7] and the curves revised to fit all the available data. The scatter of the data is considerable. The Sverdrup-Munk-Bretschneider curves give satisfactory results for deep water. For shallow water there exists an additional variable, the depth of water, which limits the maximum wave height and period and is expected to alter also the statistical distribution of wave heights and periods. Observations indicate that the wave heights are smaller in shallow water than under similar deep water conditions, but insofar as it is known, there were no comprehensive laboratory studies available for the characteristics of waves in shallow water although Keulegan has gathered considerable, as yet unpublished, laboratory data at the Bureau of Standards.

The primary concern of this study was to investigate wind-tides and the characteristics of wind-generated waves in shallow water. The experiments were made with several water depths, each combined with five different wind velocities. To investigate the bottom roughness effect, the experiments were made in three sets: (a) smooth bottom, (b) rough bottom, and (c) rough bottom and strips of cheese-cloth in a channel to simulate the roughness effects of vegetation in nature. Besides the comprehensive wave measurements, the position of the mean water level and the vertical wind velocity distribution, measured by the use of a Pitot tube, were obtained for each run. All of the results concerning the wave characteristics are given in this report; the rest of the data, such as the water-surface roughness and the wind setup are presented in separate reports (8,9).

DEFINITIONS

The definitions used in this report are as follows:

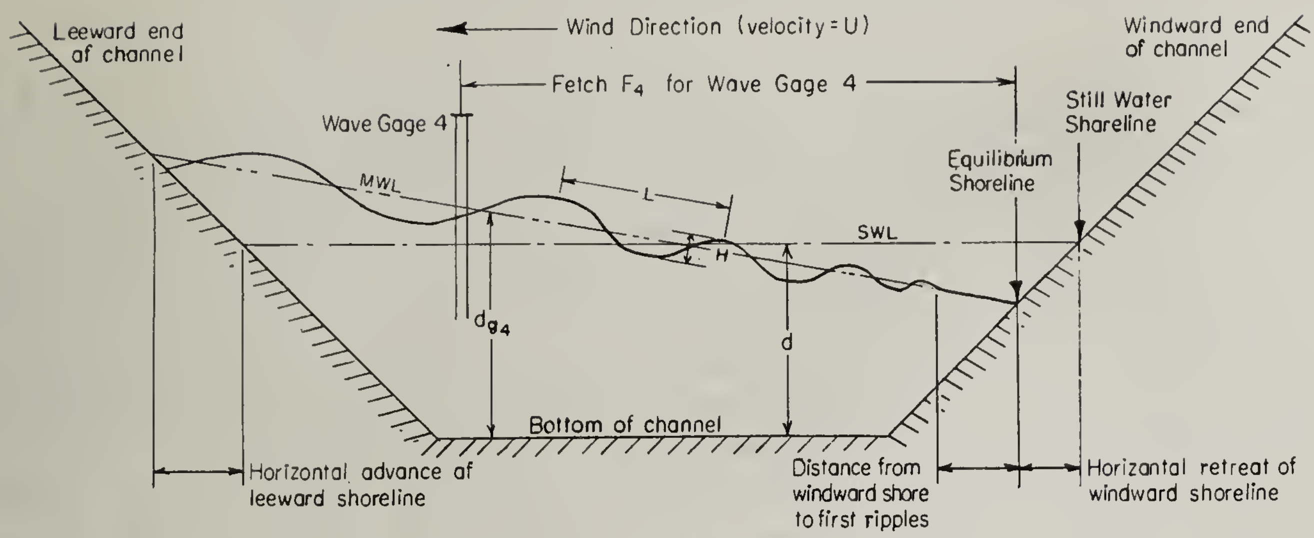


Figure 1

C wave velocity $C = L/T$, in ft/sec.

d still-water depth (bottom to SWL), in ft.

d_g the depth of water at the location the wave measurements were made (bottom to MWL), in ft.

F the fetch, defined as the distance parallel to the wind direction measured from the equilibrium shoreline (when the body of water is under wind action) to the point wave measurements were made, in ft.

g the acceleration of gravity ($g = 32.17$ ft/sec^2).

H_{mean} the mean wave height, defined as the arithmetic average of all the waves in a group of 100 waves. The single wave height is defined as the vertical distance between crest and preceding trough, in feet.

$H_{1/3}$ the significant wave height - the arithmetic average of the highest one-third of the waves, in feet.

H_{max} the maximum wave height of a group of 100 waves, in feet.

h the wind setup, the vertical distance between SWL and MWL, in feet.

L_{mean} the average wave length for a group of 100 waves. Wave length is the horizontal distance between successive wave crests measured perpendicular to the crest, in feet.

$L_{1/3}$ the average length of the longest one-third of the waves.

L_{max} the maximum wave length of a group of 100 waves.

^{-}o the subscript "o" refers to the deep water conditions (such as H_o, L_o, T_o, when $d/L > 0.5$).

MWL the mean water level.

SWL the still-water level; the surface of the water if all wave and wind action were to cease.

T_{mean} the average of all the wave periods of a group of 100 waves.

$T_{1/3}$ the average of the longest one-third of the periods in a group of 100 waves.

T_{max} the longest period in a group of 100 waves.

$T_{H_{mean}}$ the average wave period to the mean wave height H_{mean} ($T_{H_{mean}} = T_{mean}$)

$T_{H_{1/3}}$ the average period of the highest one-third of the waves ($T_{H_{1/3}} \leq T_{1/3}$).

$T_{H_{max}}$ the period of the highest wave in a group of 100 waves ($T_{H_{max}} \leq T_{max}$).

t duration of wind in seconds.

U_{av} the average wind velocity (ft/sec), defined as the total discharge of air per second divided by the area between MWL and the top of the channel.

LABORATORY EQUIPMENT AND PROCEDURE

Experiments were performed in a channel 1.0 foot wide, 60 feet long and 1.28 feet deep as shown in Figure 2a. The channel was constructed of wood, with one side made of plate-glass for observation purposes. The wind was generated by a blower mounted at one end of the channel, driven by an A.C. motor. The wind velocities could be varied from zero to approximately 50 ft/sec. by varying the air intake area at the blower. To straighten the wind flow upon entering the channel, a honey-comb was set between the blower and the channel. To guide the wind gradually on and off the water surface, a sloping beach (slope approximately 1:10) was set at the beginning and the end of the channel, as shown in Figure 2a. The downwind (leeward) beach served also to make the waves break and dissipate their energy and reduce the effect of wave reflections. The discharge of air was measured by a Venturi meter mounted as shown in Figure 2a. This Venturi meter was used to obtain approximately the desired wind velocity. Final wind velocity measurements were made, however, by using a Pitot tube mounted on a point gage.

The wave heights and periods were measured at four locations, as indicated in Figure 2a, by double-wire resistance elements connected to Brush recorders. A sample wave record is given in Figure 3.

Piezometer openings were installed on the top and the bottom of the channel at five locations along the centerline. The piezometer openings were connected to micro-manometers as shown in Figure 2b. This arrangement was made so that the manometers could be read against the inside pressure (the actual MWL) and against the atmospheric pressure. The difference between these two readings indicated the inside pressure, and therefore the pressure drop between successive manometers could be determined and corrections applied where necessary. To check this latter measurement, three draft gages were connected to the piezometer openings on the top of the channel at the locations of manometers 1, 3, and 5, as shown in Figure 2a. Pressure readings were made simultaneously with those of the manometers. These two always agreed very closely. Any difference indicated a faulty connection or a clogging of the piezometer openings and corrections could be made at once.

Procedure

The desired wind velocity was obtained by adjusting the air inlet of the blower to proper size. The blower then was shut off and the ends of the channel were closed so that no draft could occur along the channel. When the water surface had calmed completely, the SWL was determined at the location of each of the five manometers. Then the blower was started and the wave recorder started at once, so that the initial generation of waves and the gradual change of water surface elevation under wind action could be studied. Zero time was considered

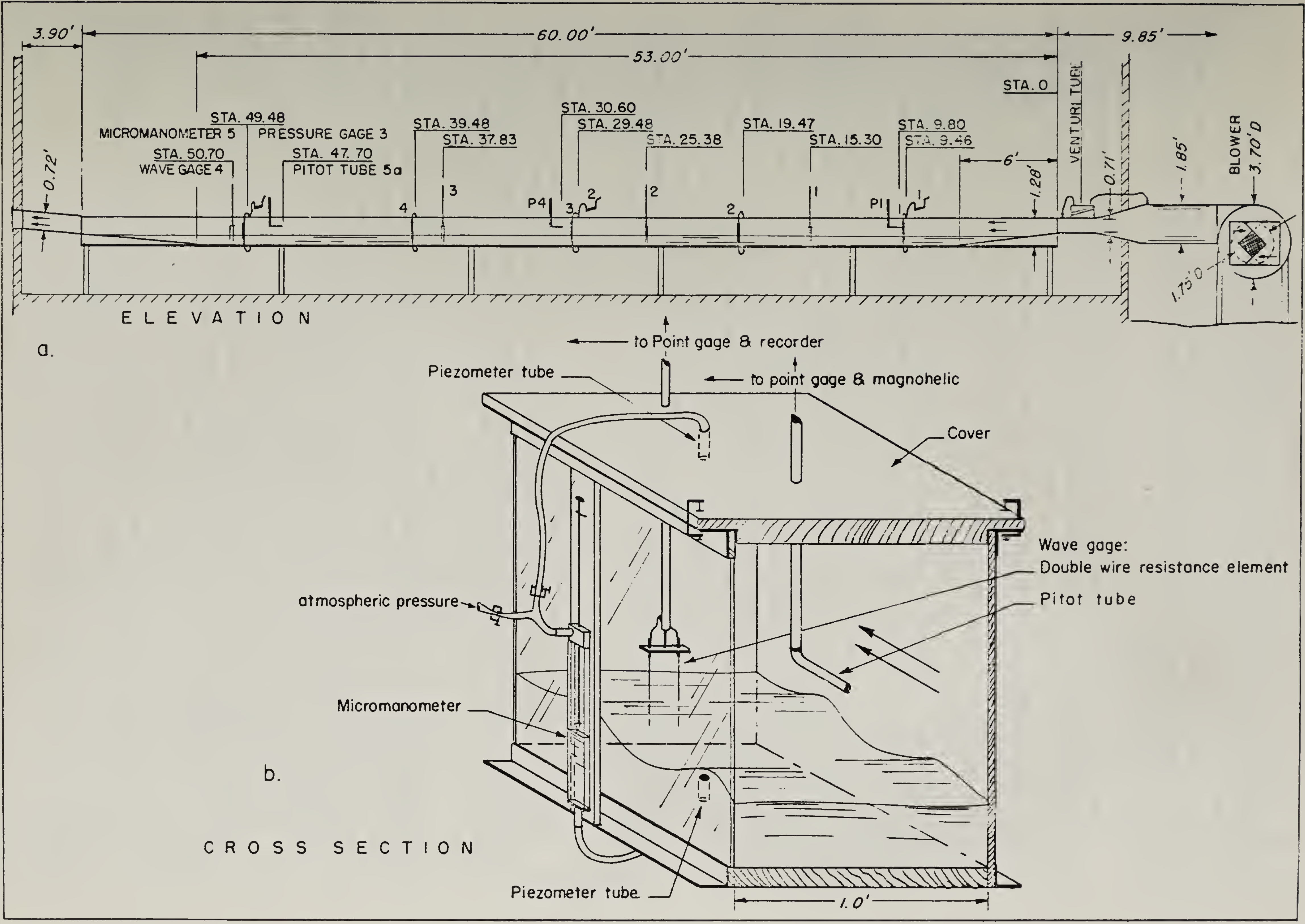


FIGURE 2 · GENERAL LABORATORY SET-UP FOR STUDY OF WIND WAVES IN SHALLOW WATER

to be the moment the blower was started and was marked accordingly on the surface elevation-time history records. The initial record was taken from zero to two minutes, the following record in intervals at: 5 min., 10 min., 15 min., 30 min., and the last after 1 hour from the beginning of the experiment. The length of each interval was at least the time necessary for 100 waves to pass a fixed point, but was usually somewhat longer.

The wind velocities were measured at three different locations along the centerline of the channel (P1, P4, and P5a in Figure 2a). Observations indicated a slight increase in velocity towards the leeward end of the channel. The increase was due to the set-up of the MWL and to increased wave heights at the end of the channel which reduced the wind passage area. This phenomenon was the most pronounced for deep water depths. However, the difference in average wind velocities at the opposite channel ends never exceeded 5 or 6 per cent and the average for the channel was always very closely represented by the average velocity at P4. For shallower water depths and lower wind velocities it was found that the average velocities were almost unchanged along the centerline of the channel. As a conclusion of this investigation the velocity profiles in later experiments were obtained only at P4, which meant a considerable saving in time. For each run a continuous wind velocity profile between the wave crests and the top of the channel was observed. When the surface elevation-time records indicated that the equilibrium condition between the wind and gravitational forces were reached, the position of MWL was measured by the use of micro-manometers at locations as indicated in Figure 2a. The wave motion was damped in the line to the micro-manometer so that the reading was the MWL directly.

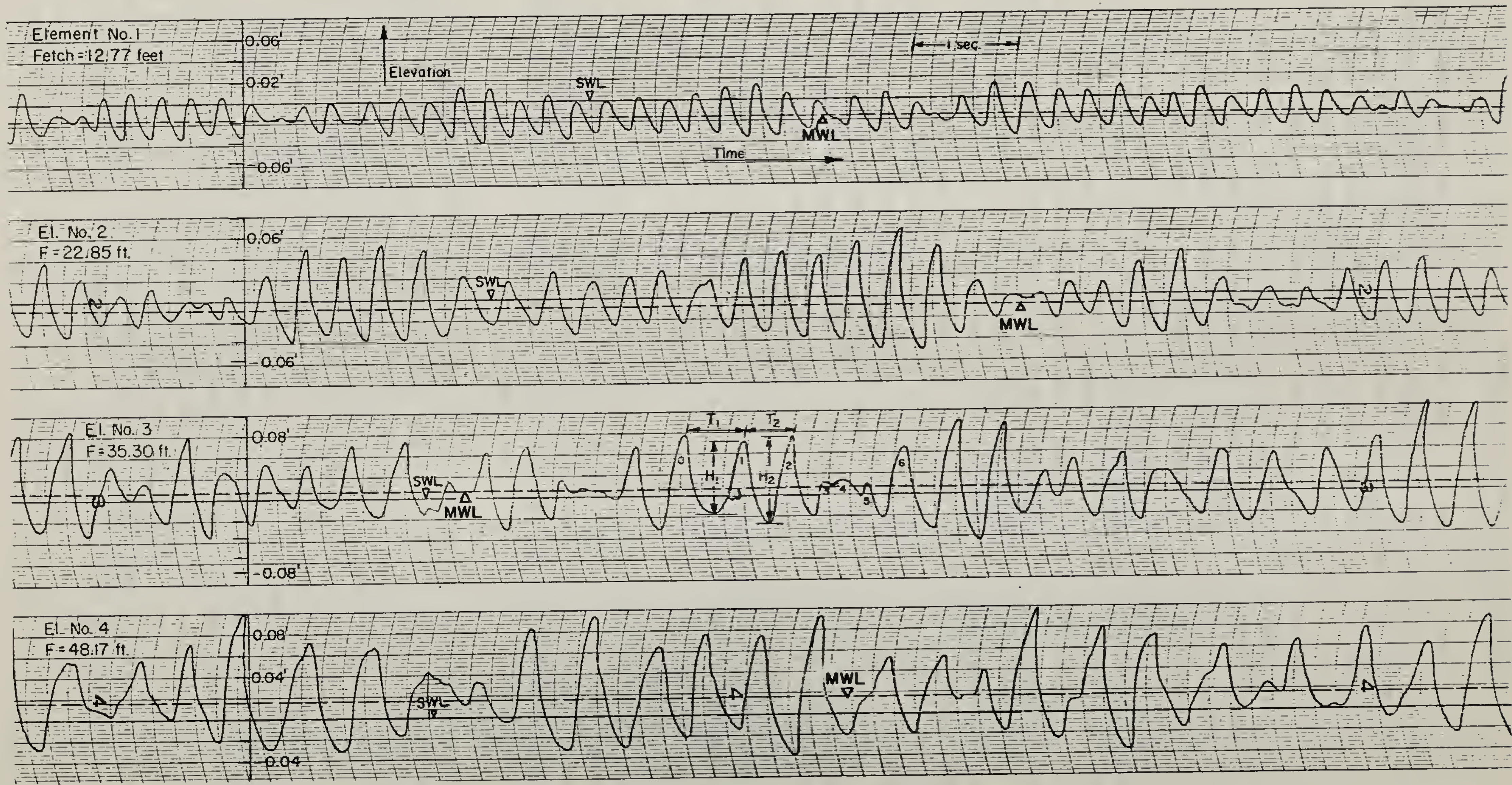
Additional measurements made for each run included the horizontal retreat of windward shore line and advance of leeward shore line under wind action, the distance from windward shore to the first ripples on the water surface, the barometric pressure, and the dry-and wet-bulb temperatures of a sling psychrometer. The barometric pressure did not show any appreciable changes during a set of experiments. The range of pressures for all the experiments during the seven months period was between 29.876 and 30.594 inches of mercury with an average value very close to 30.000 inches. The sling psychrometer measurements were taken outside the channel just before the air entered the channel. The computed unit weight of the air did not undergo any appreciable changes. The average value was approximately 0.076 lb/ft^3 with a range between 0.0742 and 0.0784 lb/ft^3 for the seven-month test period. The complete data is given in Reference 9, Table I, under the proper run numbers. The fetch F was measured from the windward shore line to the point where the waves were measured, as indicated in Figure 1.

To study the effect of bottom roughness, the experiments were made with: (a) a smooth bottom with seven different still-water depths, (b) a rough bottom (bed roughened by means of expanded metal lath) with five different still-water depths, and (c) a rough bottom and strips of cheese cloth in the channel at 1-foot intervals to simulate the roughness effects of vegetation in nature. This bottom condition was combined with four different still-water depths.

EVALUATION OF THE DATA

A sample wave record is shown in Figure 3. First it was decided to evaluate the mean, significant, and maximum wave heights and periods as a function of wind duration, t. Difficulties arose, however, in selecting the proper wave groups to be analyzed. The characteristics of the waves under laboratory conditions change very rapidly during the first few minutes of the experiment, and so the standard group of 100 waves could not be considered for, say, t = 10; 20; 30 etc. seconds. To get at least some estimate of the wave characteristics, groups of 15 waves were analyzed, and the time when the center of the group passed the point of measurement was taken as the representative time for the whole group. A sample of such data is given in Figure 4 for the wave heights. Scatter was usually considerable, especially for small values of t where the length of the evaluated wave groups was the shortest and the changes in wave characteristics the most drastic. For larger t values, longer wave groups could be evaluated and the results scattered less than with the shorter groups. Using the method as just described to analyze the data for various water depths and wind velocities, it was established that the waves obtained a more or less constant characteristic for $t > 15$ minutes. It was decided, therefore, to analyze only this portion of the data for the remaining experiments where the duration of the wind was long enough to allow an equilibrium condition to be established between the wind intensity, mean water-surface, and the waves. The data given in this report, therefore, pertain to a wind duration of at least one-half hour and a wave group of 100 waves, unless otherwise stated. The group of 100 waves in the laboratory compares favorably with the data obtained in the ocean from a continuous 20-minute wave record. On the Pacific Coast of the United States, the average wave period is approximately 12 seconds, hence a 20-minute record contains about 100 waves. On the Atlantic Coast and the Great Lakes, the average period of the waves may be considerably shorter and so the 20-minute record may include 400 or more waves. Hence, to standardize the method of evaluation, it seems to be reasonable to use always a certain number of waves rather than a specified time interval.

The group of 100 waves was chosen so as to be a fair representative of the total record, including both high and low waves. A wave was defined as that condition where a definite crest and trough occurred, regardless of its height or length. All the single crests in a given group were numbered from 0 to 99 and the wave heights and periods measured as shown in Figure 3 and tabulated in Table I. The mean wave height, H_{mean}, and period, T_{mean}, were found as the arithmetic average of the group. Next, the 33 highest waves in the group were marked and the arithmetic averages found for these waves. These values were called the significant wave height, $H_{1/3}$, and the period corresponding to this significant wave height, $T_{H1/3}$. H_{max} was the highest wave present in the given group and and T_{Hmax} the period corresponding to the maximum wave height. The wave periods also were considered individually by selecting the 33 longest



Wind velocity U = 26.30 feet/second   Still water depth d = 0.375 foot   Channel with rough bottom

FIGURE 3 · TIME HISTORY FOR SURFACE ELEVATION AT FOUR POINTS ALONG ℄ OF CHANNEL SAMPLE OF RUN 102

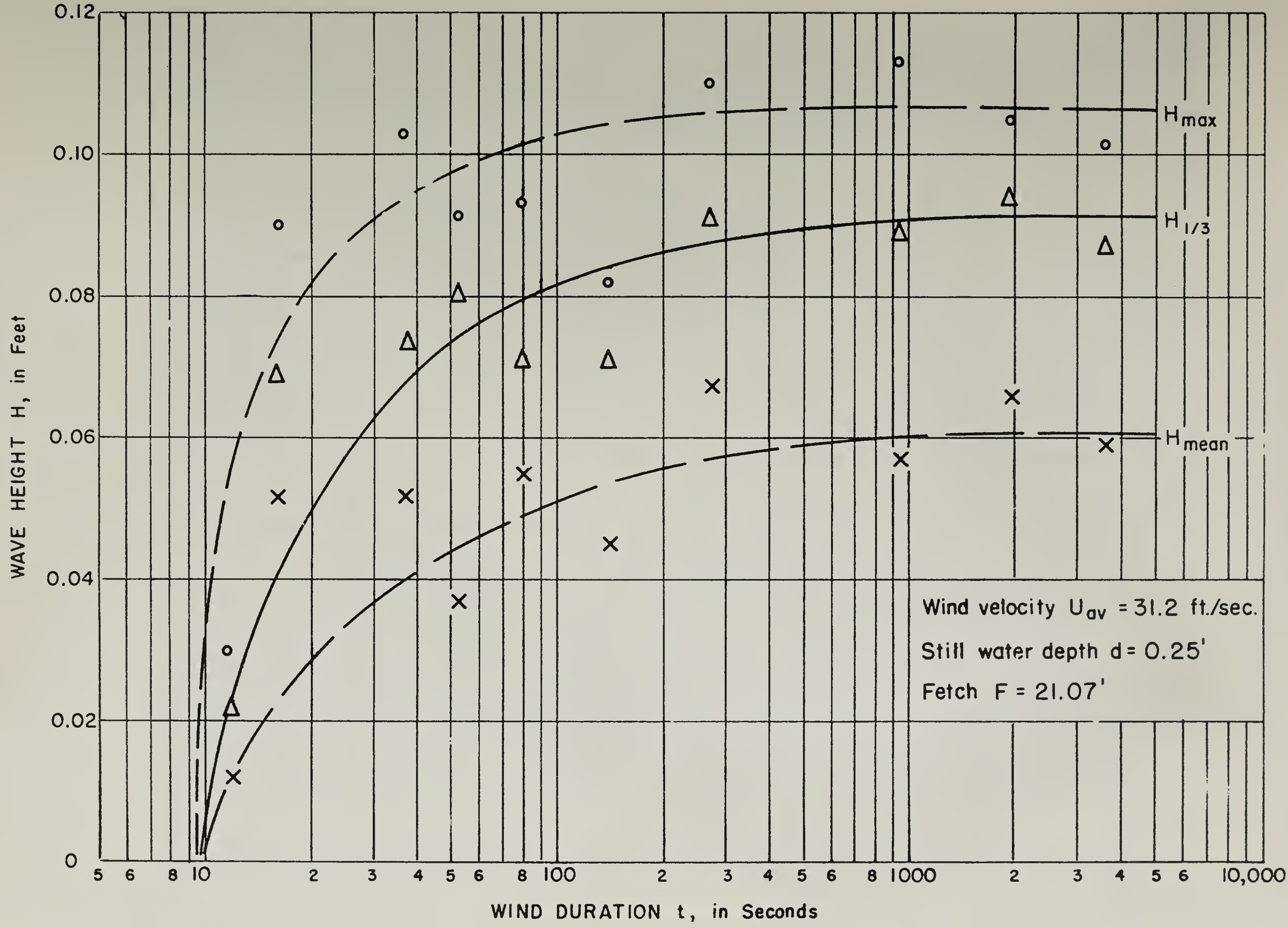


FIGURE 4 · WAVE HEIGHT AS A FUNCTION OF WIND DURATION

TABLE I

WIND WAVE MEASUREMENTS
IN THE LABORATORY WAVE CHANNEL

RUN NO.	BOTTOM ROUGHN.	DEPTH OF WATER d_g (ft.)	AVERAGE WIND VELOCITY U_{av} (ft./sec.)	FETCH F (ft.)	WAVE HEIGHT MEAN H_{mean} (ft.)	WAVE HEIGHT SIGN $H_{\frac{1}{3}}$ (ft.)	WAVE HEIGHT MAX. H_{max} (ft.)	WAVE PERIOD MEAN T_{mean} (sec)	WAVE PERIOD SIGN. $T_{\frac{1}{3}}$ (sec.)	WAVE PERIOD MAX T_{max} (sec)	WAVE PERIODS FOR MAX. AND SIGN. WAVE HEIGHTS $T_{H_{1/3}}$ (SEC)	$T_{H_{MAX.}}$ (SEC)	$\frac{gF}{U^2}$	H_o (ft.)	$\frac{H_{\frac{1}{3}}}{H_o}$	$\frac{d_g}{H_o}$	T_o (sec.)	$\frac{T_{\frac{1}{3}}}{T_o}$	$\frac{d_g}{5.12T_o^2} = \frac{d_g}{L_o}$	HORIZONTAL RETREAT OF WINDWARD SHORELINE (ft.)	HORIZONTAL ADVANCE OF LEEWARD SHORELINE (ft.)	DISTANCE FROM WINDWARD SHORE TO FIRST RIPPLES (ft.)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
12	smooth	0.370	10.05	12.85	VERY	SMALL																
		0.370		22.72	0.005	0.009	0.017	0.15	0.19	0.22	0.18	0.20	7.27	0.024	0.370	15.416						
		0.370		35.38	0.020	0.026	0.032	0.21	0.25	0.30	0.23	0.23	11.32	0.030	0.866	12.333	0.32	0.78	0.788			
		0.370		48.25	0.030	0.031	0.038	0.28	0.34	0.48	0.29	0.30	15.44	0.034	0.910	10.880	0.35	0.97	0.592			
13	"	0.370	14.10	13.02	0.003	0.006	0.010	0.12	0.17	0.20	0.14	0.18	2.08	0.028	0.214	13.214						
		0.370		22.89	0.017	0.039	0.049	0.22	0.27	0.35	0.24	0.28	3.66	0.035	1.114	10.571						
		0.370		35.55	0.042	0.057	0.075	0.31	0.36	0.42	0.32	0.30	5.69	0.043	1.325	8.604	0.37	0.97	0.528			
		0.370		48.42	0.044	0.068	0.090	0.37	0.46	0.55	0.39	0.38	7.75	0.049	1.390	7.551	0.40	1.15	0.451			
14	"	0.370	19.25	13.05	0.011	0.019	0.023	0.19	0.24	0.30	0.21	0.23	1.13	0.039	0.487	9.487						
		0.370		22.92	0.038	0.061	0.090	0.29	0.36	0.50	0.30	0.32	1.99	0.051	1.196	7.254						
		0.370		35.58	0.060	0.088	0.124	0.37	0.43	0.50	0.38	0.40	3.09	0.081	1.442	6.065	0.44	0.97	0.372			
		0.375		48.45	0.058	0.083	0.110	0.44	0.53	0.70	0.46	0.47	4.21	0.070	1.185	5.357	0.48	1.10	0.318			
15	"	0.365	25.60	12.70	0.029	0.044	0.057	0.27	0.32	0.40	0.29	0.30	0.62	0.055	0.800	6.636						1.50
		0.370		22.57	0.066	0.094	0.126	0.37	0.43	0.30	0.37	0.40	1.11	0.069	1.362	5.362						
		0.375		35.23	0.072	0.102	0.140	0.41	0.51	0.60	0.46	0.40	1.73	0.084	1.214	4.464	0.52	0.98	0.271			
		0.385		48.10	0.079	0.109	0.158	0.55	0.66	0.90	0.53	0.60	2.36	0.096	1.135	4.010	0.56	1.17	0.239			
16	"	0.350	33.40	12.30	0.036	0.048	0.064	0.31	0.37	0.43	0.31	0.30	0.35	0.073	0.657	4.794				0.67	1.40	0.90
		0.360		22.17	0.063	0.101	0.128	0.37	0.49	0.55	0.44	0.45	0.64	0.094	1.074	3.829						
		0.360		34.83	0.087	0.116	0.128	0.49	0.63	0.75	0.58	0.60	1.00	0.114	1.017	3.333	0.61	1.03	0.199			
		0.395		47.70	0.100	0.144	0.175	0.58	0.77	0.94	0.64	0.65	1.37	0.130	1.107	3.038	0.65	1.18	0.182			
17	"	0.285	33.0	11.75	0.028	0.044	0.062	0.28	0.34	0.42	0.31	0.30	0.35	0.071	0.619	4.014				0.55	1.13	1.10
		0.290		21.62	0.061	0.083	0.118	0.40	0.45	0.53	0.41	0.40	0.64	0.091	0.912	3.186						
		0.310		34.28	0.053	0.085	0.120	0.42	0.59	0.70	0.54	0.40	1.01	0.112	0.758	2.767	0.60	0.98	0.168			
		0.320		47.15	0.114	0.137	0.155	0.66	0.78	0.85	0.72	0.48	1.39	0.129	1.062	2.480	0.68	1.18	0.143			
18	"	0.290	25.20	12.03	0.022	0.031	0.041	0.23	0.28	0.36	0.26	0.20	0.81	0.053	0.584	5.471				0.18	0.58	1.40
		0.300		21.90	0.043	0.068	0.085	0.34	0.41	0.30	0.35	0.38	1.11	0.067	1.014	4.477						
		0.305		34.58	0.059	0.094	0.120	0.37	0.47	0.30	0.42	0.30	1.75	0.083	1.132	3.674	0.52	0.90	0.220			
		0.310		47.53	0.057	0.091	0.130	0.44	0.56	0.70	0.50	0.43	2.41	0.095	0.957	3.283	0.56	1.00	0.192			
19	"	0.295	20.30	12.05	0.010	0.015	0.021	0.17	0.21	0.30	0.20	0.20	0.94	0.041	0.365	7.195				0.18	0.45	2.30
		0.300		21.92	0.031	0.049	0.070	0.29	0.33	0.43	0.30	0.30	1.71	0.053	0.924	5.660						
		0.300		34.58	0.041	0.059	0.085	0.37	0.44	0.52	0.40	0.43	2.70	0.064	0.921	4.687	0.48	0.95	0.278			
		0.305		47.45	0.043	0.072	0.103	0.40	0.49	0.60	0.45	0.45	3.71	0.074	0.972	4.121	0.49	1.00	0.248			
20	"	0.300	18.30	12.20	0.004	0.006	0.008	0.12	0.16	0.25	0.13	0.13	1.48	0.032	0.187	9.375						
		0.300		22.07	0.019	0.029	0.043	0.22	0.28	0.30	0.24	0.24	2.67	0.041	0.707	7.317						
		0.300		34.73	0.039	0.059	0.076	0.30	0.35	0.40	0.32	0.33	4.20	0.030	1.180	6.000	0.40	0.87	0.386			
		0.300		47.60	0.039	0.056	0.085	0.39	0.46	0.66	0.39	0.40	5.76	0.060	0.933	5.000	0.44	1.04	0.302			
21	"	0.300	11.20	12.20	VERY	SMALL							3.12	0.021		14.285				0.03	0.08	7.00
		0.300		22.07	0.004	0.005	0.008	0.17	0.21	0.25	0.17	0.16	5.65	0.027	0.185	11.111						
		0.300		34.73	0.016	0.025	0.030	0.23	0.28	0.40	0.25	0.23	8.89	0.033	0.757	9.090	0.33	0.84	0.537			
		0.300		47.60	0.032	0.043	0.056	0.30	0.32	0.40	0.29	0.30	12.19	0.038	1.131	7.894	0.36	0.88	0.430			
22	"	0.230	31.20	11.20	0.034	0.050	0.068	0.28	0.32	0.40	0.31	0.30	0.37	0.064	0.781	3.593				0.45	1.30	0.80
		0.240		21.07	0.063	0.090	0.106	0.38	0.45	0.52	0.37	0.33	0.70	0.085	1.058	2.823						
		0.255		33.73	0.064	0.090	0.104	0.44	0.58	0.66	0.51	0.45	1.11	0.103	0.873	2.475	0.58	1.00	0.148			
		0.270		46.60	0.094	0.130	0.168	0.60	0.76	0.90	0.64	0.44	1.54	0.120	1.083	2.230	0.62	1.22	0.137			
23	"	0.240	25.0	11.30	0.021	0.039	0.046	0.23	0.31	0.35	0.25	0.27	0.59	0.051	0.764	4.705				0.23	0.70	1.50
		0.250		21.37	0.044	0.068	0.091	0.34	0.42	0.48	0.36	0.31	1.10	0.066	1.030	3.787						
		0.250		34.03	0.058	0.080	0.098	0.42	0.52	0.60	0.43	0.42	1.75	0.080	1.000	3.125	0.51	1.01	0.187			
		0.260		46.90	0.058	0.086	0.102	0.42	0.55	0.63	0.47	0.48	2.42	0.093	0.924	2.795	0.55	1.00	0.168			
24	"	0.245	20.40	11.52	0.010	0.015	0.019	0.20	0.23	0.28	0.21	0.22	0.89	0.040	0.375	6.125				0.13	0.48	2.35
		0.250		21.39	0.034	0.044	0.052	0.28	0.32	0.36	0.29	0.30	1.85	0.053	0.830	4.716						
		0.250		34.05	0.046	0.068	0.084	0.36	0.40	0.49	0.36	0.32	2.63	0.065	1.046	3.846	0.46	0.86	0.230			
		0.255		46.92	0.048	0.070	0.082	0.40	0.48	0.58	0.42	0.45	3.63	0.074	0.945	3.445	0.49	0.97	0.207			
25	"	0.250	15.20	11.60	0.008	0.012	0.014	0.12	0.16	0.19	0.13	0.13	1.61	0.029	0.413	8.821				0.08	0.18	3.60
		0.250		21.47	0.024	0.030	0.037	0.22	0.28	0.34	0.24	0.22	2.99	0.038	0.789	8.578						
		0.250		34.13	0.038	0.054	0.067	0.31	0.37	0.40	0.31	0.32	4.75	0.046	1.173	5.434	0.39	0.94	0.321			
		0.250		47.00	0.042	0.059	0.070	0.37	0.42	0.55	0.37	0.38	6.54	0.053	1.113	4.718	0.41	1.02	0.290			
26	"	0.230	11.10	11.67	VERY	SMALL							3.05	0.020		12.500						8.40
		0.250		21.54	0.004	0.007	0.013	0.16	0.21	0.25	0.17	0.20	5.62	0.026	0.269	9.615						
		0.250		34.20	0.021	0.030	0.037	0.22	0.27	0.30	0.23	0.24	8.93	0.033	0.909	7.575	0.33	0.81	0.448			
		0.250		47.07	0.027	0.036	0.045	0.28	0.32	0.40	0.28	0.25	12.29	0.038	0.947	6.578	0.35	0.91	0.400			
27	"	0.200	10.70	11.15	VERY	SMALL							3.13	0.019		10.526				0.08	0.05	6.30
		0.200		21.02	0.003	0.005	0.007	0.13	0.18	0.25	0.13	0.13	5.91	0.025	0.200	8.000						
		0.200		33.68	0.010	0.018	0.024	0.19	0.24	0.31	0.21	0.22	9.46	0.031	0.580	6.451	0.32	0.75	0.383			
		0.200		46.55	0.021	0.030	0.038	0.28	0.31	0.40	0.27	0.27	13.08	0.034	0.882	5.882	0.35	0.88	0.320			
28	"	0.195	15.80	11.18	0.004	0.006	0.009	0.14	0.19	0.26	0.15	0.14	1.44	0.029	0.206	6.724				0.02	0.14	3.50
		0.200		21.05	0.038	0.055	0.073	0.23	0.28	0.40	0.26	0.30	2.71	0.039	1.410	5.128						
		0.200		33.71	0.035	0.054	0.073	0.30	0.37	0.47	0.31	0.33	4.35	0.048	1.125	4.166	0.39	0.94	0.257			
		0.205		46.58	0.041	0.055	0.070	0.39	0.45	0.55	0.39	0.33	6.00	0.055	1.000	3.727	0.42	1.07	0.227			
29	"	0.190	20.0	11.03	0.019	0.030	0.044	0.18	0.21	0.30	0.19	0.18	0.89	0.039	0.769	4.871				0.17	0.22	2.25
		0.200		20.90	0.032	0.047	0.062	0.30	0.34	0.45	0.30	0.30	1.68	0.051	0.921	3.921						
		0.200		33.56	0.029	0.043	0.066	0.35	0.43	0.55	0.37	0.40	2.70	0.062	0.693	3.225	0.45	0.95	0.193			
		0.210		48.43	0.033	0.049	0.074	0.42	0.53	0.85	0.45	0.40	3.73	0.068	0.720	3.088	0.48	1.10	0.178			

RUN NO	BOTTOM ROUGHN.	DEPTH OF WATER d_g (ft)	AVERAGE WIND VELOCITY U_{av} (ft/sec)	FETCH F (ft.)	WAVE HEIGHT MEAN H_{mean} (ft.)	WAVE HEIGHT SIGN $H_{1/3}$ (ft)	WAVE HEIGHT MAX H_{max} (ft)	WAVE PERIOD MEAN T_{mean} (sec.)	WAVE PERIOD SIGN $T_{1/3}$ (sec)	WAVE PERIOD MAX T_{max} (sec.)	WAVE PERIODS FOR MAX. AND SIGN. WAVE HEIGHTS $T_{H_{1/3}}$ (SEC)	$T_{H_{MAX}}$ (SEC)	$\frac{gF}{U^2}$	H_o (ft)	$\frac{H_{1/3}}{H_o}$	$\frac{d_g}{H_o}$	T_o (sec)	$\frac{T_{1/3}}{T_o}$	$\frac{d_g}{5.12 T_o^2} = \frac{d_g}{L_o}$	HORIZONTAL RETREAT OF WINDWARD SHORELINE (ft)	HORIZONTAL ADVANCE OF LEEWARD SHORELINE (ft)	DISTANCE FROM WINDWARD SHORE TO FIRST RIPPLES (ft.)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
30	smooth	0 190	24 30	10 97	0 020	0 030	0.045	0 24	0 28	0 30	0.24	0.30	0.60	0.048	0 625	3 958				0 22	0 42	1 15
		0 200		2084	0 046	0 067	0 090	0 35	0 41	0.50	0.37	0.40	1.14	0.064	1.046	3 125						
		0 200		33 50	0 046	0 068	0 090	0 39	0 49	0 60	0.42	0.41	1.83	0.079	0 860	2 531	0 51	0 96	0 150			
		0 210		46 37	0 042	0 062	0 080	0 44	0 55	0 66	0.48	0.43	2 53	0 090	0 688	2.333	0.54	1 01	0.140			
51	"	0.180	50.50	10 67	0 025	0 036	0 050	0.29	0 35	0 40	0.30	0.32	0 37	0.061	0 590	2 950						
		0.190		20 54	0 056	0 077	0 100	0 38	0 45	0 50	0.40	0.45	0 71	0 081	0.950	2 345						
		0.210		33 20	0 054	0 081	0 110	0 42	0.54	0.70	0.49	0.55	1.15	0 101	0.801	2 079	0 58	0 93	0 122			
		0 225		46 07	0.071	0.103	0 130	0 44	0 60	0 77	0.49	0.34	1 59	0.116	0.887	1.939	0 62	0 96	0 114			
52	"	0 130	28.70	10 10	0 022	0 034	0 047	0 26	0 31	0 40	0.29	0.26	0.39	0 056	0.607	2 321				0 65	1.00	0.65
		0.145		19 97	0 038	0.060	0.072	0 35	0 43	0 55	0.39	0.40	0.78	0.074	0 810	1.959						
		0.165		32 63	0 046	0 068	0 090	0 40	0 51	0 70	0.46	0.44	1.27	0.092	0.739	1 793	0 55	0 92	0 106			
		0.180		45.50	0.055	0 084	0.110	0 44	0 60	0 81	0.52	0.61	1 77	0.108	0.777	1.666	0 59	1.01	0 101			
53	"	0.140	24.0	10 45	0 019	0 029	0 042	0.24	0 28	0 36	0.25	0.22	0.58	0.047	0.617	2.978				0.22	0.35	0.90
		0.150		20 32	0 032	0.050	0 072	0 30	0.36	0 45	0.32	0.40	1 13	0 063	0 793	2.380						
		0.160		32 98	0 035	0 054	0 080	0 37	0 48	0.60	0.40	0.40	1.84	0 077	0 701	2 077	0.50	0.96	0.125			
		0.165		45 85	0 026	0.042	0.053	0 36	0 48	0 75	0.40	0.37	2.56	0.088	0 477	1.875	0.54	0 88	0 110			
54	"	0.140	20 50	10.53	0 009	0.014	0 021	0.19	0.22	0.30	0.20	0.20	0.81	0 039	0 358	3 589				0.09	0.27	2.80
		0 150		2040	0.029	0 042	0 052	0 28	0 34	0 63	0.30	0.27	1.56	0.052	0 807	2 884						
		0.155		3306	0 038	0.055	0.072	0 37	0.43	0 52	0.38	0.40	2.53	0.064	0 859	2 421	0.46	0.93	0 142			
		0.160		4593	0 030	0.049	0 078	0 36	0 47	0 60	0.43	0.40	3 51	0.073	0.671	2.191	0 48	0 97	0.135			
35	"	0.145	15.50	1060	VERY	SMALL							1 42	0.028		5.178				0.02	0.22	3.70
		0.150		20.47	0 020	0 030	0.047	0.20	0 23	0 32	0.21	0.23	2.74	0.037	0.810	4 054						
		0.150		33.13	0 029	0 048	0 083	0 29	0 33	0.44	0.29	0.28	4.44	0.046	1 043	3 260	0.38	0 86	0.203			
		0.155		46.00	0 031	0 047	0 076	0.36	0 44	0.75	0.38	0.37	6.16	0.054	0.870	2 870	0.41	1.07	0.180			
36	"	0.150	10.90	10.62	VERY	SMALL							2.88	0.019		7.894				0.02	0.07	5.40
		0 150		20.49	0 004	0 006	0 010	0 13	0.16	0 20	0.14	0.17	5.55	0.025	0 240	6 000						
		0.150		33.15	0 012	0.018	0.024	0 20	0.26	0.30	0.21	0.20	8 98	0 031	0.580	4 838	0 32	0.81	0.287			
		0 150		46.02	0.016	0.025	0.033	0.27	0.31	0.40	0.27	0.28	12.46	0.036	0 694	4 166	0.35	0.88	0.240			
57	"	0.060	31.50	7.60	0 010	0.014	0.020	0.21	0.26	0.32	0.23	0.22	0.25	0.056	0 250	1 071				2.56	1 45	0.50
		0.090		17.47	0.011	0 020	0.028	0 20	0.32	0.37	0.24	0.37	0.57	0 080	0.250	1 125						
		0.120		30.13	0 037	0.054	0.070	0.37	0 46	0.54	0.41	0.40	0 98	0.099	0.545	1 212	0.58	0 79	0 069			
		0.150		43 00	0 040	0.064	0.085	0 37	0.50	0 68	0.43	0.46	1.38	0.117	0.547	1 282	0.62	0.80	0 076			
38	"	0.085	24 40	9 85	0 011	0.016	0.019	0.20	0 24	0.30	0.22	0.24	0.53	0.046	0.347	1 847				0.22	0.45	1.00
		0.100		19.72	0.021	0.031	0.042	0.27	0.34	0.40	0.31	0.30	1.06	0.063	0.492	1 587						
		0.110		32 60	0 029	0.046	0 062	0 36	0 43	0.50	0.39	0.41	1.76	0.078	0.589	1.410	0.50	0.86	0.085			
		0.120		45 25	0.032	0.046	0.060	0 37	0 48	0 64	0.41	0.42	2.44	0 089	0.516	1.348	0.54	0.88	0 080			
39	"	0.090	20.40	9.96	0.008	0.012	0.016	0.19	0.22	0.28	0.20	0.22	0.77	0 038	0.315	2 368				0.13	0.27	1.90
		0.100		19.83	0.016	0.023	0.035	0.26	0.30	0.42	0.28	0.28	1.53	0.050	0.460	2.000						
		0.110		32 71	0.017	0.028	0 038	0 30	0.38	0.48	0.33	0.32	2.53	0.063	0.444	1.746	0.46	0.82	0.101			
		0.115		45.36	0 020	0.035	0.056	0.31	0.44	0.50	0.41	0.42	3 51	0 072	0.486	1.597	0.48	0.91	0.097			
40	"	0 095	15.80	10 10	0.002	0.003	0.005	0.12	0.15	0.19	0. 13	0.14	1 30	0 029	0 103	3.275				0 02	0.18	4.00
		0.100		19 97	0.014	0 022	0.029	0.21	0.25	0.37	0.23	0.22	2.37	0 038	0.578	2.631						
		0 105		32 85	0.017	0.027	0.040	0.29	0.35	0.40	0.30	0.34	4 23	0 047	0.374	2 234	0.39	0.89	0.134			
		0.110		45 50	0 021	0 033	0.040	0 32	0.39	0.46	0.35	0.30	5.86	0.054	0.611	2.037	0.42	0 92	0.122			
41	"	0.100	11 40	10 10	0 0009	0.0013	0.0023	0.11	0.13	0.17	0.11	0.15	2 50	0.019	0 069	5.263				0.01	0.03	6.80
		0.100		19 93	0 003	0 005	0 008	0.14	0.17	0.22	0. 15	0.15	4 93	0.026	0.193	3 846						
		0.100		32 85	0 010	0.014	0.021	0 18	0 23	0.30	0.21	0.22	8.13	0.033	0.424	3.030	0 33	0 69	0.179			
		0.100		45 50	0.014	0 022	0.030	0 26	0.30	0.38	0.26	0.26	11.26	0.038	0.578	2.631	0.36	0.83	0.150			
42	"	0	30.30			NO WAVES														17 00	1.02	0.40
		0.020		3.17	VERY	SMALL							0.11									
		0.080		15.23	0.013	0.023	0.030	0.22	0.29		0.26	0.25	0.53	0.071	0 323	1.126	0.49	0.59	0.065			
		0 110		28 10	0.023	0.039	0.060	0.27	0.37	0 44	0.35	0.38	0.98	0.093	0.419	1.182	0.36	0.66	0.068			
45	"	0.015	23 90	2 00	VERY	SMALL							0.11	0.025		0.600				7.63	0.47	1.20
		0.050		11 87	0.006	0.009	0.012	0 16	0.22	0.30	0.18	0.20	0 67	0.048	0 187	1.041						
		0.070		24 53	0 012	0 018	0 036	0.26	0.31	0.35	0.29	0.27	1.38	0 067	0.268	1 044	0.47	0.65	0.061			
		0 085		37 40	0.008	0.015	0.025	0 24	0.35	0.52	0.31	0.33	2.11.	0.080	0.187	1.062	0.31	0.68	0.063			
44	"	0.030	19 90	7.50	VERY	SMALL							0.61	0.033						2.15	0.37	2.40
		0.050		17.37	0 007	0.010	0.013	0 17	0 20	0 26	0.19	0.18	1 41	0.047	0.212	1.063						
		0.065		30 03	0 011	0.017	0.024	0 24	0.29	0.33	0.26	0.22	2.44	0.059	0.288	1.101	0.44	0.65	0.065			
		0.073		42.90	0.006	0 011	0.020	0.19	0.30	0 40	0.27	0.30	3.48	0.068	0 159	1.088	0.47	0.63	0.066			
45	"	0.040	16 0	9 49	VERY	SMALL							1.19	0.028		1.428				0.16	0.18	3.00
		0.050		19 36	0.004	0.006	0.010	0.15	0.18	0.20	0.16	0.12	2.4[illegible]	0.038	0.157	1.313						
		0.060		32.02	0.006	0.010	0.015	0.19	0.22	0.30	0.20	0.20	4 02	0.048	0.208	1.230	0.39	0.56	0.077			
		0.065		44 89	0.011	0.016	0 020	0.23	0.27	0.30	0.26	0.28	5 64	0.060	0.268	1.083	0.42	0 64	0.072			
46	"	0.045	11 20	9 58	VERY	SMALL							2.46	0.019		2.368				0.06	0.03	12.50
		0.050		19 45	VERY	SMALL		0 11	0.14	0.17			4.99	0.025		2.000						
		0.055		32.11	0.003	0.004	0 006	0.16	0.18	0.20	0.17	0.18	8.23	0.032	0.125	1.718	0.33	0.57	0.098			
		0.060		44.98	VERY	SMALL							11.53	0.037		1 621	0.35		0 096			

MTD-7024

RUN NO	BOTTOM ROUGHN.	DEPTH OF WATER d_g (ft)	AVERAGE WIND VELOCITY U_{av} (ft/sec)	FETCH F (ft)	WAVE HEIGHT MEAN H_{mean} (ft)	SIGN $H_{1/3}$ (ft)	MAX H_{max} (ft)	WAVE PERIOD MEAN T_{mean} (sec.)	SIGN. $T_{1/3}$ (sec.)	MAX T_{max} (sec)	WAVE PERIODS FOR MAX. AND SIGN. WAVE HEIGHTS $T_{H_{1/3}}$ (SEC)	$T_{H_{MAX.}}$ (SEC)	$\frac{gF}{U^2}$	H_o (ft)	$\frac{H_{1/3}}{H_o}$	$\frac{d_g}{H_o}$	T_o (sec)	$\frac{T_{1/3}}{T_o}$	$\frac{d_g}{5.12 T_o^2} = \frac{d_g}{L_o}$
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
101	rough	0.385	32.70	12.35	0.048	0.063	0.080	0.34	0.39	0.48	0.35	0.35	0.37	0.071	0.89	5.00	0.50	0.78	0.277
		0.365		22.43	0.081	0.109	0.138	0.43	0.51	0.58	0.47	0.48	0.88	0.092	1.18	3.97	0.56	0.91	0.277
		0.380		34.88	0.087	0.132	0.173	0.47	0.83	0.72	0.58	0.50	1.05	0.111	1.19	3.42	0.61	1.03	0.199
		0.395		47.75	0.118	0.160	0.190	0.58	0.75	0.90	0.67	0.76	1.44	0.127	1.26	3.11	0.65	1.15	0.182
102	"	0.385	28.30	12.77	0.029	0.041	0.047	0.28	0.33	0.46	0.29	0.28	0.59	0.056	0.74	6.52	0.44	0.75	0.369
		0.370		22.85	0.049	0.074	0.110	0.37	0.41	0.52	0.38	0.40	1.06	0.072	1.03	5.15	0.49	0.84	0.301
		0.375		35.30	0.055	0.089	0.132	0.40	0.53	0.84	0.45	0.48	1.84	0.088	1.01	4.28	0.53	1.00	0.260
		0.380		48.17	0.069	0.107	0.150	0.48	0.81	0.80	0.56	0.62	2.24	0.100	1.07	3.80	0.57	1.07	0.228
103	"	0.385	21.60	12.85	0.016	0.021	0.027	0.23	0.26	0.32	0.24	0.24	0.89	0.045	0.46	8.11	0.39	0.87	0.488
		0.370		22.93	0.040	0.055	0.078	0.32	0.37	0.52	0.32	0.28	1.68	0.058	0.95	8.38	0.44	0.84	0.374
		0.370		35.38	0.053	0.080	0.104	0.38	0.48	0.84	0.39	0.38	2.44	0.070	1.14	8.29	0.48	0.96	0.314
		0.375		48.25	0.060	0.089	0.125	0.45	0.54	0.64	0.46	0.46	3.33	0.080	1.11	4.89	0.51	1.06	0.282
104	"	0.370	16.85	12.93	0.004	0.007	0.010	0.15	0.18	0.24	0.17	0.18	1.50	0.034	0.20	10.89	0.33	0.58	0.881
		0.370		23.01	0.023	0.033	0.040	0.25	0.28	0.38	0.26	0.26	2.67	0.043	0.76	8.60	0.38	0.74	0.500
		0.370		35.46	0.048	0.062	0.075	0.34	0.39	0.46	0.34	0.34	4.12	0.062	1.20	7.12	0.41	0.95	0.430
		0.370		48.33	0.051	0.077	0.094	0.40	0.47	0.82	0.39	0.34	5.81	0.060	1.27	6.17	0.44	1.07	0.374
106	"	0.370	12.00	12.97	VERY SMALL			0.14	0.19	0.30			2.90	0.023		18.09	0.27	0.70	1.000
		0.370		23.05	0.009	0.014	0.024	0.21	0.24	0.32	0.20	0.22	5.15	0.030	0.47	12.33	0.31	0.77	0.755
		0.370		35.50	0.026	0.037	0.046	0.27	0.30	0.34	0.28	0.26	7.93	0.038	1.02	10.27	0.35	0.88	0.588
		0.370		48.37	0.035	0.048	0.057	0.34	0.38	0.48	0.33	0.36	10.81	0.041	1.17	9.02	0.37	1.03	0.529
108	"	0.060	32.40	4.80	0.0022	0.0035	0.0055	0.17	0.22	0.28	0.18	0.20	0.15	0.047	0.07	1.28	0.43	0.51	0.063
		0.100		14.88	0.015	0.024	0.042	0.24	0.30	0.34	0.27	0.29	0.46	0.076	0.32	1.32	0.51	0.59	0.075
		0.130		27.33	0.032	0.051	0.068	0.34	0.43	0.64	0.38	0.43	0.84	0.099	0.52	1.31	0.57	0.75	0.078
		0.155		40.20	0.049	0.068	0.089	0.47	0.60	0.83	0.52	0.54	1.23	0.118	0.58	1.31	0.62	0.97	0.079
107	"	0.085	25.20	9.80	0.010	0.015	0.022	0.22	0.27	0.34	0.23	0.23	0.50	0.048	0.31	1.77	0.41	0.86	0.099
		0.095		19.88	0.015	0.022	0.032	0.29	0.35	0.44	0.32	0.36	1.01	0.065	0.34	1.46	0.46	0.78	0.087
		0.110		32.33	0.024	0.035	0.048	0.36	0.43	0.50	0.36	0.40	1.64	0.080	0.44	1.38	0.51	0.84	0.083
		0.120		45.20	0.020	0.030	0.045	0.38	0.45	0.57	0.40	0.42	2.29	0.092	0.33	1.31	0.55	0.82	0.077
108	"	0.090	20.70	9.94	0.008	0.012	0.018	0.19	0.23	0.39	0.20	0.22	0.75	0.038	0.32	2.37	0.38	0.64	0.138
		0.100		20.02	0.016	0.024	0.030	0.27	0.32	0.38	0.29	0.28	1.50	0.052	0.48	1.92	0.41	0.78	0.118
		0.105		32.47	0.015	0.025	0.036	0.34	0.41	0.51	0.35	0.37	2.44	0.064	0.39	1.64	0.48	0.89	0.098
		0.115		45.34	0.017	0.026	0.035	0.37	0.44	0.54	0.38	0.38	3.41	0.074	0.35	1.58	0.49	0.90	0.093
109	"	0.095	18.20	10.09	0.0013	0.0025	0.0060	0.15	0.20	0.28	0.16	0.17	1.24	0.029	0.09	3.28	0.31	0.65	0.194
		0.100		20.17	0.013	0.019	0.025	0.23	0.27	0.33	0.24	0.24	2.47	0.039	0.49	2.57	0.36	0.75	0.152
		0.105		32.62	0.015	0.024	0.033	0.29	0.34	0.42	0.31	0.30	4.00	0.049	0.49	2.14	0.40	0.85	0.128
		0.110		45.49	0.018	0.026	0.037	0.34	0.38	0.45	0.34	0.35	5.58	0.056	0.48	1.97	0.43	0.88	0.116
110	"	0.100	11.30	10.17	VERY SMALL								2.56	0.019		5.26	0.25		0.313
		0.100		20.25	0.003	0.006	0.008	0.16	0.20	0.28	0.18	0.18	5.10	0.026	0.23	3.85	0.29	0.89	0.232
		0.100		32.70	0.012	0.017	0.020	0.24	0.27	0.35	0.23	0.23	8.24	0.033	0.52	3.03	0.33	0.82	0.179
		0.105		45.57	0.015	0.022	0.029	0.29	0.32	0.47	0.29	0.26	11.48	0.037	0.59	2.84	0.36	0.89	0.159
111	"	0.180	31.20	10.67	0.027	0.044	0.077	0.26	0.32	0.40	0.29	0.30	0.35	0.063	0.70	2.86	0.47	0.68	0.159
		0.195		20.75	0.042	0.062	0.083	0.37	0.47	0.56	0.41	0.40	0.69	0.083	0.75	2.35	0.53	0.89	0.135
		0.210		33.20	0.066	0.100	0.117	0.43	0.55	0.65	0.48	0.48	1.10	0.103	0.97	2.04	0.58	0.95	0.122
		0.225		46.07	0.070	0.109	0.133	0.45	0.63	0.88	0.58	0.72	1.52	0.118	0.92	1.91	0.63	1.00	0.111
112	"	0.190	25.30	10.96	0.021	0.032	0.042	0.24	0.29	0.40	0.24	0.30	0.55	0.050	0.64	3.80	0.41	0.71	0.221
		0.200		21.04	0.030	0.048	0.060	0.32	0.39	0.53	0.34	0.38	1.06	0.067	0.72	2.99	0.47	0.83	0.177
		0.205		33.49	0.057	0.083	0.115	0.39	0.50	0.64	0.40	0.45	1.88	0.082	1.01	2.50	0.52	0.96	0.147
		0.210		46.36	0.040	0.065	0.093	0.42	0.56	0.65	0.49	0.50	2.33	0.094	0.69	2.24	0.55	1.02	0.136
113	"	0.195	20.90	11.05	0.009	0.015	0.026	0.20	0.24	0.33	0.21	0.20	0.81	0.041	0.37	4.75	0.39	0.62	0.250
		0.200		21.13	0.033	0.049	0.070	0.28	0.33	0.40	0.30	0.30	1.56	0.053	0.92	3.78	0.42	0.79	0.222
		0.205		33.58	0.047	0.066	0.098	0.36	0.43	0.50	0.38	0.40	2.47	0.066	1.00	3.11	0.46	0.94	0.188
		0.210		46.45	0.037	0.055	0.070	0.40	0.50	0.62	0.44	0.40	3.42	0.078	0.72	2.77	0.50	1.00	0.184
114	"	0.195	16.80	11.13	VERY SMALL			0.15	0.19	0.22			1.27	0.032		6.10	0.32	0.59	0.375
		0.200		21.21	0.026	0.038	0.047	0.25	0.29	0.32	0.26	0.28	2.42	0.042	0.90	4.77	0.37	0.78	0.288
		0.200		33.66	0.041	0.060	0.084	0.32	0.39	0.45	0.34	0.40	3.84	0.051	1.18	3.92	0.41	0.95	0.233
		0.205		46.53	0.037	0.055	0.068	0.39	0.47	0.55	0.39	0.31	5.30	0.059	0.93	3.48	0.44	1.07	0.207
118	"	0.200	11.50	11.15	0.0028	0.0048	0.0075	0.13	0.17	0.30	0.13	0.13	2.71	0.021	0.23	9.52	0.26	0.65	0.572
		0.200		21.23	0.006	0.010	0.013	0.19	0.22	0.26	0.19	0.20	5.16	0.027	0.35	7.41	0.30	0.73	0.435
		0.200		33.68	0.022	0.032	0.046	0.26	0.31	0.34	0.27	0.27	8.19	0.033	0.99	8.06	0.33	0.94	0.357
		0.200		46.55	0.031	0.044	0.060	0.33	0.36	0.40	0.32	0.30	11.32	0.039	1.12	5.13	0.36	1.00	0.303
116	"	0	31.25		NO WAVES														
		0																	
		0.075		11.83	0.017	00.[illegible]	0.050	0.23	0.29	0.36	0.25	0.34	0.39	0.066	0.42	1.14	0.48	0.80	0.064
		0.105		24.70	0.032	0.047	0.064	0.35	0.43	0.50	0.38	0.42	0.81	0.091	0.52	1.15	0.55	0.78	0.068
117	"	0	24.90		NO WAVES														
		0.045		6.88	0.006	0.009	0.013	0.16	0.20	0.26	0.18	0.22	0.36	0.040	0.23	1.13	0.38	0.53	0.081
		0.070		19.33	0.020	0.029	0.037	0.26	0.32	0.38	0.28	0.28	1.00	0.063	0.47	1.11	0.45	0.71	0.067
		0.090		32.20	0.017	0.026	0.038	0.32	0.40	0.52	0.34	0.34	1.67	0.079	0.33	1.15	0.51	0.78	0.068
118	"	0.025	20.90	2.70	VERY SMALL								0.20	0.022		1.14	0.29		0.058
		0.050		12.78	0.008	0.012	0.016	0.18	0.22	0.48	0.19	0.22	0.94	0.043	0.27	1.16	0.38	0.58	0.068
		0.065		25.23	0.017	0.023	0.027	0.26	0.31	0.48	0.28	0.27	1.86	0.058	0.39	1.12	0.44	0.70	0.068
		0.080		38.10	0.015	0.022	0.028	0.30	0.37	0.42	0.33	0.26	2.81	0.069	0.31	1.18	0.48	0.77	0.068
119	"	0.040	16.20	7.43	VERY SMALL								0.91	0.026		1.54	0.29		0.093
		0.045		17.51	0.006	0.010	0.014	0.17	0.21	0.28	0.19	0.20	2.15	0.037	0.26	1.22	0.35	0.60	0.071
		0.055		29.96	0.011	0.017	0.020	0.22	0.27	0.34	0.24	0.25	3.67	0.047	0.36	1.17	0.39	0.89	0.071
		0.065		42.83	0.007	0.012	0.016	0.24	0.31	0.40	0.25	0.24	5.25	0.055	0.22	1.18	0.42	0.74	0.072
120	"	0.045	11.60	9.54	VERY SMALL								2.28	0.020		2.25	0.25	•	0.141
		0.050		19.62		0.020	0.050	0.13	0.17	0.24		•	4.69	0.027	0.74	1.85	0.30	0.57	0.109
		0.055		32.07	0.007	0.010	0.014	0.17	0.19	0.24	0.18	0.20	7.68	0.033	0.31	1.67	0.33	0.58	0.098
		0.055		44.94	0.008	0.013	0.017	0.20	0.24	0.32	0.22	0.23	10.74	0.038	0.34	1.45	0.36	0.87	0.083

RUN NO	BOTTOM ROUGHN.	DEPTH OF WATER d_g (ft)	AVERAGE WIND VELOCITY U_{av} (ft/sec)	FETCH F (ft)	WAVE HEIGHT MEAN H_{mean} (ft)	WAVE HEIGHT SIGN $H_{\frac{1}{3}}$ (ft)	WAVE HEIGHT MAX H_{max} (ft)	WAVE PERIOD MEAN T_{mean} (sec)	WAVE PERIOD SIGN $T_{\frac{1}{3}}$ (sec)	WAVE PERIOD MAX T_{max} (sec)	WAVE PERIODS FOR MAX. AND SIGN. WAVE HEIGHTS $T_{H_{1/3}}$ (SEC)	$T_{H_{MAX.}}$ (SEC)	$\frac{gF}{U^2}$	H_o (ft)	$\frac{H_{\frac{1}{3}}}{H_o}$	$\frac{d_g}{H_o}$	T_o (sec)	$\frac{T_{\frac{1}{3}}}{T_o}$	$\frac{d_g}{5.12 T_o^2} = \frac{d_g}{L_o}$
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
121	rough + veget	0.175	31.00	10.57	0.024	0.035	0.048	0.28	0.34	0.42	0.29	0.32	0.35	0.062	0.56	2.82	0.47	0.72	0.155
		0.190		20.65	0.044	0.061	0.073	0.38	0.47	0.60	0.41	0.47	0.69	0.083	0.73	2.29	0.53	0.89	0.132
		0.210		33.10	0.047	0.073	0.099	0.41	0.56	0.66	0.49	0.47	1.11	0.102	0.72	2.06	0.58	0.97	0.122
		0.230		45.97	0.066	0.093	0.106	0.53	0.72	0.93	0.62	0.50	1.54	0.118	0.79	1.95	0.62	1.16	0.117
122	•	0.190	24.90	10.97	0.016	0.025	0.037	0.24	0.29	0.38	0.27	0.28	0.57	0.049	0.51	3.88	0.41	0.71	0.221
		0.195		21.05	0.039	0.056	0.075	0.34	0.40	0.52	0.36	0.37	1.08	0.065	0.86	3.00	0.46	0.87	0.179
		0.205		33.50	0.042	0.065	0.085	0.39	0.48	0.56	0.42	0.40	1.74	0.080	0.81	2.56	0.51	0.94	0.154
		0.215		46.37	0.037	0.058	0.071	0.44	0.55	0.67	0.46	0.41	2.41	0.092	0.63	2.34	0.55	1.00	0.139
123	•	0.195	20.90	11.10	0.007	0.012	0.023	0.21	0.26	0.31	0.22	0.25	0.82	0.041	0.29	4.76	0.37	0.70	0.279
		0.200		21.18	0.027	0.037	0.048	0.31	0.36	0.41	0.31	0.32	1.56	0.054	0.69	3.70	0.42	0.86	0.222
		0.205		33.63	0.044	0.064	0.086	0.38	0.44	0.52	0.39	0.32	2.48	0.065	0.98	3.15	0.46	0.96	0.188
		0.210		46.50	0.036	0.053	0.069	0.45	0.51	0.61	0.43	0.39	3.42	0.076	0.70	2.76	0.50	1.02	0.168
124	•	0.200	16.85	11.18	0.0017	0.0033	0.0066	0.15	0.19	0.24	0.16	0.17	1.27	0.032	0.10	6.25	0.32	0.59	0.385
		0.200		21.26	0.010	0.015	0.023	0.24	0.28	0.33	0.26	0.24	2.41	0.042	0.36	4.76	0.37	0.76	0.286
		0.200		33.71	0.024	0.031	0.040	0.31	0.34	0.37	0.32	0.30	3.82	0.052	0.60	3.85	0.41	0.83	0.233
		0.205		46.58	0.029	0.038	0.055	0.36	0.40	0.47	0.36	0.33	5.28	0.060	0.63	3.42	0.41	0.91	0.207
125	•	0.200	11.70	11.20									2.63	0.021		9.52	0.26		0.571
		0.200		21.28		NO WAVES							5.00	0.028		7.14	0.30		0.435
		0.200		33.73									7.93	0.034		5.88	0.34		0.339
		0.200		46.70									10.97	0.039		5.13	0.37		0.286
126	•	0.355	33.20	12.42	0.043	0.064	0.092	0.31	0.37	0.48	0.33	0.31	0.36	0.072	0.89	4.93	0.51	0.73	0.267
		0.360		22.50	0.066	0.097	0.138	0.39	0.47	0.60	0.44	0.42	0.66	0.093	1.08	3.87	0.56	0.84	0.224
		0.375		34.95	0.078	0.127	0.162	0.46	0.64	1.02	0.58	0.56	1.02	0.113	1.12	3.32	0.61	1.05	0.197
		0.395		47.82	0.119	0.154	0.185	0.58	0.73	1.02	0.61	0.70	1.40	0.129	1.19	3.06	0.65	1.12	0.182
127	•	0.365	26.00	12.73	0.029	0.042	0.063	0.27	0.31	0.40	0.28	0.28	0.61	0.055	0.76	6.64	0.43	0.72	0.384
		0.365		22.81	0.051	0.074	0.098	0.35	0.41	0.46	0.37	0.42	1.09	0.071	1.04	5.14	0.48	0.85	0.309
		0.375		35.26	0.060	0.089	0.124	0.39	0.49	0.62	0.43	0.40	1.68	0.086	1.03	4.36	0.53	0.92	0.260
		0.380		48.13	0.060	0.107	0.141	0.45	0.58	0.78	0.50	0.56	2.29	0.098	1.09	3.88	0.57	1.02	0.229
128	•	0.365	21.80	12.83	0.020	0.030	0.041	0.23	0.27	0.32	0.25	0.24	0.87	0.046	0.65	7.93	0.39	0.69	0.468
		0.370		22.91	0.048	0.072	0.096	0.32	0.37	0.44	0.34	0.35	1.53	0.056	1.24	6.38	0.44	0.84	0.374
		0.370		35.36	0.052	0.076	0.106	0.39	0.46	0.54	0.40	0.42	2.39	0.070	1.09	5.29	0.48	0.96	0.314
		0.375		48.23	0.069	0.096	0.117	0.47	0.54	0.60	0.46	0.46	3.26	0.081	1.19	4.63	0.51	1.06	0.282
129	•	0.365	18.70	12.91	0.007	0.012	0.018	0.18	0.21	0.28	0.19	0.22	1.49	0.034	0.35	10.74	0.33	0.64	0.652
		0.370		22.99	0.031	0.044	0.056	0.27	0.30	0.34	0.29	0.27	2.68	0.043	1.02	8.60	0.38	0.79	0.500
		0.370		35.44	0.047	0.064	0.082	0.34	0.39	0.44	0.34	0.28	4.07	0.052	1.23	7.12	0.41	0.95	0.430
		0.375		48.31	0.048	0.072	0.100	0.41	0.46	0.68	0.41	0.36	5.57	0.059	1.22	6.36	0.44	1.05	0.379
130	•	0.370	11.30	12.96	0.001	0.002	0.005	0.13	0.17	0.26	0.14	0.14	3.15	0.022	0.09	16.82	0.27	0.63	1.000
		0.370		23.04	0.008	0.013	0.020	0.19	0.22	0.32	0.21	0.22	5.60	0.028	0.46	13.21	0.30	0.73	0.804
		0.370		35.49	0.021	0.030	0.044	0.25	0.30	0.36	0.27	0.26	8.63	0.034	0.88	10.88	0.34	0.88	0.627
		0.375		48.56	0.033	0.045	0.065	0.33	0.38	0.44	0.33	0.33	11.76	0.039	1.15	9.61	0.36	1.06	0.560
131	•	0.055	33.10	3.30		VERY SMALL		0.13	0.17	0.26			0.10	0.041		1.34	0.41	0.41	0.064
		0.095		13.38	0.015	0.022	0.032	0.17	0.26	0.35	0.23	0.22	0.39	0.076	0.29	1.25	0.51	0.51	0.071
		0.130		25.83	0.032	0.050	0.065	0.32	0.44	0.50	0.40	0.40	0.76	0.099	0.51	1.31	0.58	0.76	0.078
		0.180		38.70	0.044	0.064	0.085	0.41	0.56	0.70	0.45	0.35	1.14	0.116	0.55	1.38	0.62	0.90	0.081
132	•	0.085	25.30	9.80	0.010	0.015	0.019	0.19	0.23	0.30	0.20	0.20	0.49	0.048	0.31	1.77	0.41	0.56	0.099
		0.095		19.88	0.016	0.025	0.033	0.26	0.33	0.40	0.29	0.27	1.00	0.065	0.38	1.46	0.46	0.72	0.087
		0.110		32.33	0.017	0.028	0.039	0.28	0.40	0.48	0.33	0.39	1.62	0.080	0.35	1.38	0.51	0.78	0.083
		0.125		45.20	0.024	0.035	0.048	0.36	0.43	0.48	0.37	0.39	2.27	0.093	0.38	1.34	0.55	0.78	0.081
133	•	0.090	21.25	9.98		VERY SMALL		0.17	0.21	0.23			0.71	0.040		2.25	0.36	0.58	0.134
		0.095		20.06	0.009	0.015	0.024	0.23	0.30	0.40	0.25	0.28	1.43	0.053	0.28	1.79	0.42	0.71	0.106
		0.105		32.51	0.010	0.018	0.034	0.21	0.30	0.38	0.27	0.28	2.32	0.066	0.27	1.59	0.47	0.84	0.093
		0.115		45.38	0.014	0.019	0.031	0.26	0.35	0.55	0.30	0.28	3.23	0.077	0.25	1.49	0.50	0.70	0.090
134	•	0.095	16.80	10.11		VERY SMALL							1.15	0.031		3.06	0.32		0.183
		0.100		20.19	0.004	0.006	0.009	0.15	0.19	0.26	0.17	0.19	2.30	0.041	0.15	2.44	0.37	0.51	0.143
		0.100		32.64	0.004	0.006	0.010	0.15	0.23	0.33	0.20	0.19	3.72	0.051	0.12	1.96	0.40	0.57	0.122
		0.105		45.51	0.006	0.009	0.017	0.19	0.23	0.29	0.20	0.20	5.19	0.059	0.15	1.78	0.44	0.52	0.106
133	•	0.100	11.80	10.18									2.35	0.021		4.78	0.28		0.285
		0.100		20.26		NO WAVES							4.68	0.028		3.57	0.30		0.217
		0.100		32.71									7.38	0.034		2.94	0.34		0.169
		0.100		45.58									10.33	0.039		2.58	0.37		0.143
136	•	0	31.80			NO WAVES													
		0																	
		0.083		11.83	0.011	0.019	0.026	0.18	0.25	0.30	0.23	0.30	0.38	0.067	0.28	1.27	0.49	0.31	0.069
		0.120		24.70	0.027	0.041	0.059	0.34	0.43	0.54	0.39	0.40	0.79	0.093	0.44	1.29	0.56	0.77	0.075
137	•	0	23.40			NO WAVES													
		0.040		7.88	0.0020	0.0035	0.0061	0.13	0.17	0.23	0.15	0.13	0.39	0.044	0.08	0.91	0.39	0.44	0.051
		0.070		20.33	0.008	0.013	0.022	0.18	0.25	0.32	0.21	0.19	1.01	0.066	0.20	1.06	0.47	0.53	0.062
		0.090		33.20	0.008	0.014	0.023	0.25	0.32	0.39	0.28	0.28	1.66	0.082	0.17	1.10	0.52	0.62	0.065
138		0.030	20.50	3.80		VERY SMALL							0.29	0.025		1.20	0.30		0.065
		0.050		13.88	0.0018	0.0031	0.0050	0.13	0.17	0.21	0.15	0.15	1.06	0.044	0.07	1.14	0.38	0.45	0.068
		0.065		26.33	0.004	0.007	0.010	0.18	0.20	0.27	0.16	0.17	2.02	0.058	0.12	1.12	0.43	0.47	0.065
		0.060		39.20	0.007	0.011	0.017	0.23	0.28	0.35	0.25	0.28	3.00	0.069	0.18	1.18	0.47	0.60	0.071

periods from the group regardless of the wave heights; and averaging this gave the significant wave period, $T_{1/3}$. The maximum wave period, T_{max}, was the longest period present in the given group regardless of the wave height. The complete data are tabulated in Table I. The wave periods given in Table I are those as evaluated from individual wave periods. The relationships between the individual wave periods and the periods corresponding to the maximum and significant wave heights are given graphically in Figure 15.

RESULTS AND DISCUSSION

Wave Heights

Wave heights are plotted in Figure 5a against the dimensionless parameters used by Sverdrup and Munk(1). This plot demonstrates clearly that the wave heights are affected by the depth of water. The shallower is the water, the more pronounced is the effect. The uppermost points are those from deep-water conditions, while the points from the shallow water lie considerably below the Sverdrup-Munk curve. This latter curve in Figure 5a was slightly altered to better fit the available data. It was found that the relationship could be represented best by a straight line on log-log paper for $gF/U^2 < 3 \times 10^4$. The equation for this straight line is:

$$gH_o/U^2 = 3.25 \times 10^{-3} (gF/U^2)^{0.435} \qquad (1)$$

or solving for H_o:

$$H_o = 4.75 \times 10^{-4} U^{1.13} F^{0.435} \qquad (2)$$

For $gF/U^2 > 3 \times 10^4$

$$gH_o/U^2 = \text{const.} = 0.25 \qquad (3)$$

and

$$H_o = 7.8 \times 10^{-3} U^2. \qquad (4)$$

In deep water the maximum wave height is controlled by the wave steepness. Studies by Michell(10), Stokes (11), Havelock (12), and others, on the problem of the greatest height obtainable by an oscillatory wave of permanent form, lead to the conclusion that in deep water the maximum steepness of a wave is 0.142. In shallow water, however, the waves usually break before they reach their maximum steepness. For a solitary wave(13), it can be shown theoretically that the relationship between the wave height at the breaking point and the water depth is:

$$H_b = 0.78 d. \qquad (5)$$

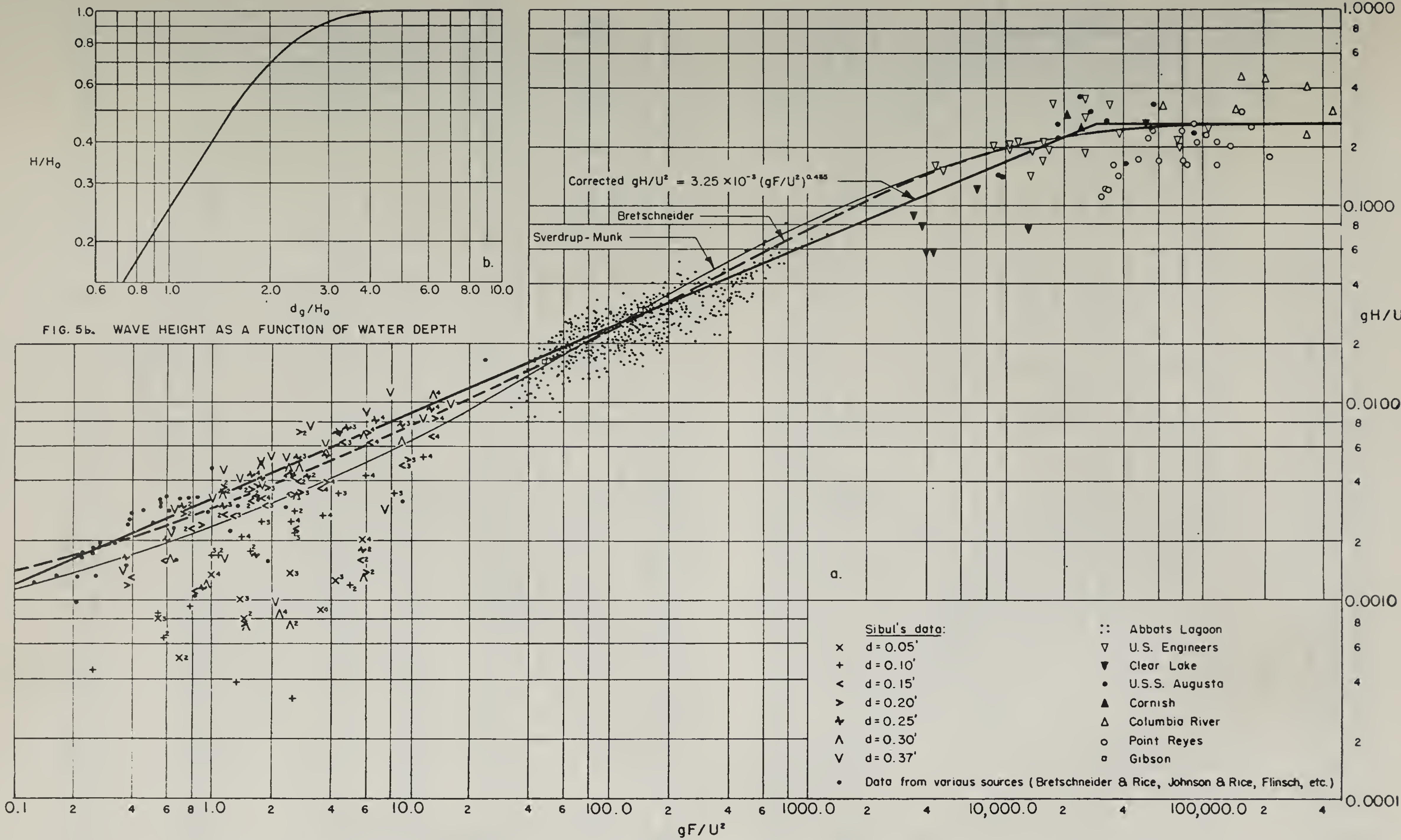


FIG. 5b. WAVE HEIGHT AS A FUNCTION OF WATER DEPTH

FIGURE 5a. WAVE HEIGHT AS A FUNCTION OF WIND VELOCITY AND FETCH

In Lake Okeechobee measurements it was shown [14] that in very shallow water the envelope curves of the highest significant waves for varying wind speeds were limited by the maximum value:

$$H_{1/3} = 0.59\ d. \tag{6}$$

Further, it was found[14] at Lake Okeechobee that the maximum wave height was 1.34, and the mean wave height 0.60, times the significant wave height. If H_b in Equation (5) is assumed to be the maximum, then the significant wave height for Lake Okeechobee could be found by dividing the right side of Equation (5) by 1.34. The result is very close to that in Equation (6). In the transitional region between that of deep water and shallow water, the wave height is affected by the wave length as well as by the depth of water. When the waves are exposed also to a strong wind action, this may cause the waves to break before they reach their maximum steepness in deep water, or the maximum height as indicated by Equation (5) for shallow water. In the present laboratory experiments $H_{1/3}/d_g$ never exceeded 0.48, or for the maximum wave height H_{max}/d_g never exceeded 0.61.

It is questionable if Equations (5) or (6) should be used to predict the maximum wave heights for shallow water. The question still remains open as to what should be considered shallow water, and the method may result in prohibitively high wave predictions for design purposes. The proper method should include the fetch and wind velocities as well as the depth of water.

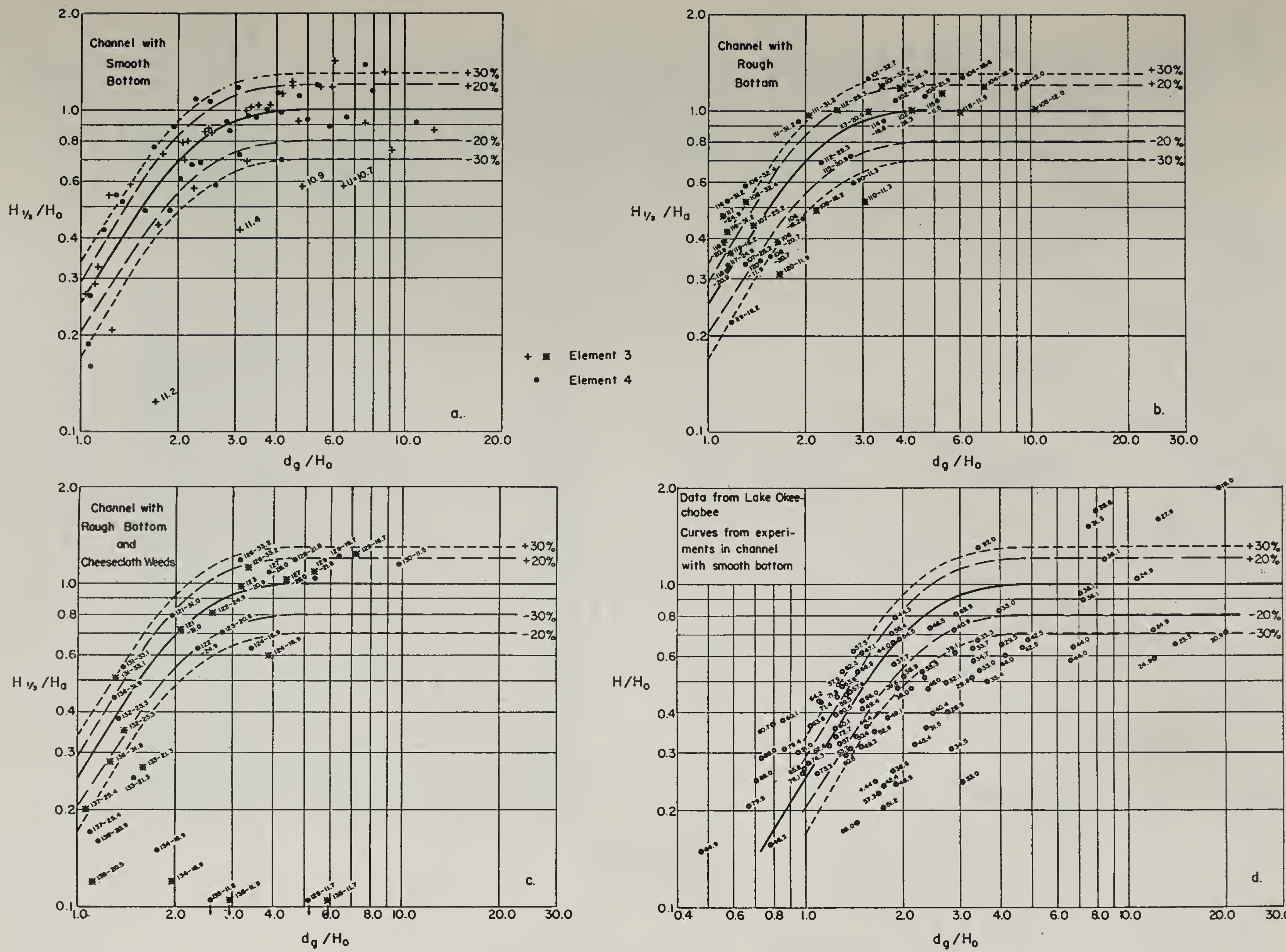
The wave heights as functions of water depth at the location of measurements were plotted in Figure 6a to d. H_o in these graphs indicates the wave height for deep water and was found from the deep-water curve shown in Figure 5a; and d_g is the water depth at the location where the waves were measured (bottom to MWL). The graphs were based on: (a) the laboratory study with a smooth-bottom; (b) the laboratory study with a rough bottom; (c) the laboratory study with a rough bottom with strips of cheese cloth in the channel to simulate the roughness effect of vegetation in nature; and (d) field measurements as made on Lake Okeechobee for wind velocities up to 90 ft/sec. and fetches up to 25 miles (Saville)[15].

<u>The smooth bottom</u> condition was represented by the painted channel bottom and had an equivalent sand roughness* of 0.0135 foot (4.1 mm.) (Manning's n = 0.0116). The wave data as obtained under this condition shows a scatter characteristic of all wave measurements, but it was relatively easy to construct an average curve through the data. 80 percent

*By equivalent sand roughness, K_s, is meant that grain size which has, according to the equation

$$f = \frac{1}{\left(2.0 \log_{10} \frac{2R}{K_s} + 1.74\right)^2}$$

for open channel flow, the same resistance, f , as the given roughness (where R is the hydraulic radius).



The Values Given Beside The Plotted Points Refer To Run Number And Wind Speed

FIGURE 6 · HEIGHT OF WIND GENERATED WAVES AS A FUNCTION OF WATER DEPTH

of the experimental points are inside the ± 30 percent error limit from this curve, and 57 percent are inside the ± 20 percent error limit. There still are some points considerably below the described curve and error limits. It is interesting to note, however, that all these points represent the conditions of the lowest wind velocities and shortest fetch lengths (Element 3).

The rough bottom condition was obtained by using expanded metal lath on the smooth bottom (see Figure 7). The equivalent sand roughness for this condition was found to be equal to 0.0635 foot (19.4 mm.) (Manning's n = 0.0207). The wave data for this condition are plotted in Figure 6b. For comparison with the smooth bottom experiments, the average curve and the ± 30 percent limits were transformed from Figure 6a. There appears to be no difference between the data as obtained with the smooth bottom and that with the rough bottom. Most of the data fit inside the ± 30 percent limit as obtained for the smooth bottom. The points below this limit are again for the conditions with the lowest wind velocities and shortest fetches, and those points above the limits are for highest wind velocities. To make the identification of points easier, run numbers and wind velocities were given for all the experimental points in Figure 6b.

The rough bottom and cheese cloth in the channel were introduced to simulate the roughness effect of vegetation in nature. The cheese cloth was fastened to the bottom across the entire width of the channel. The top of the cloth was made to float by the use of a thin piece of balsawood. The buoyancy of the cloth was kept to a minimum so that it could easily follow the current and the motion of water particles, as does the natural grass. The height of the cloth was approximately 0.30 foot and constant for all runs, hence, for the deepest depth of 0.37 foot as used in the experiments, the top of the cloth was slightly below SWL and for shallower depths it floated at SWL. One cloth was used for each foot of channel. The arrangement is shown in Figure 8. For this figure it is interesting to note that the cloth is inclined against the wave and wind direction (indicated by the arrow in the picture). This was always the case and was caused by the bottom return current which balanced the wind driven current on the water surface. Additional discussion on this phenomenon is given in Reference 9.

The wave data with simulated vegetation are plotted in Figure 6c, and compared with that from the smooth-bottom experiments. The data show considerable scatter. A closer investigation of Figure 6c shows, however, a marked regularity in scatter. The ± 30 percent error limit as found for the smooth-bottom tests includes most of the data where wind velocities were higher than 20 ft/sec. The data for $U > 20$ ft/sec. are, however, slightly below the values with a smooth bottom, as one might expect. Lower wind velocities resulted in wave heights which were considerably smaller than the corresponding heights for smooth bottom, and the wind velocities below 12 ft/sec. did not generate waves in depths less than 0.20 foot.

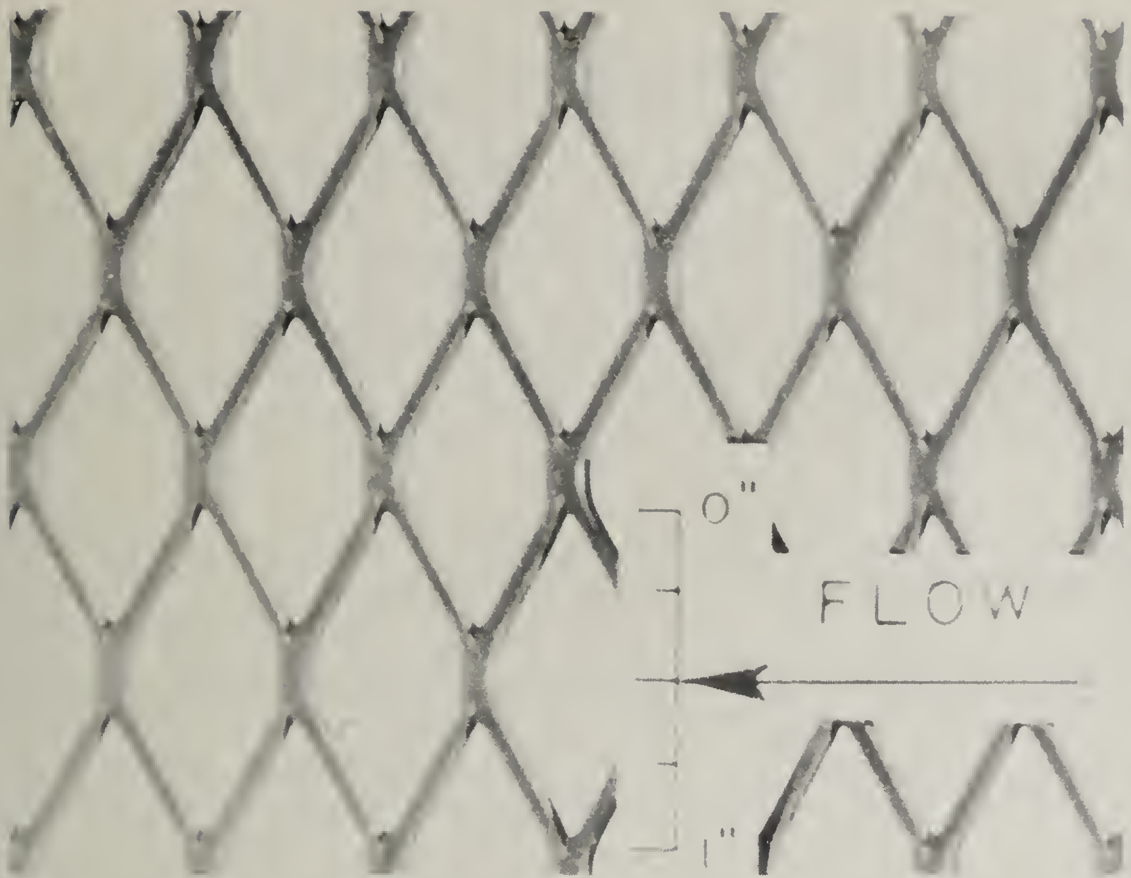


FIGURE 7 · EXPANDED METAL LATH AS USED FOR ROUGH BOTTOM IN CHANNEL

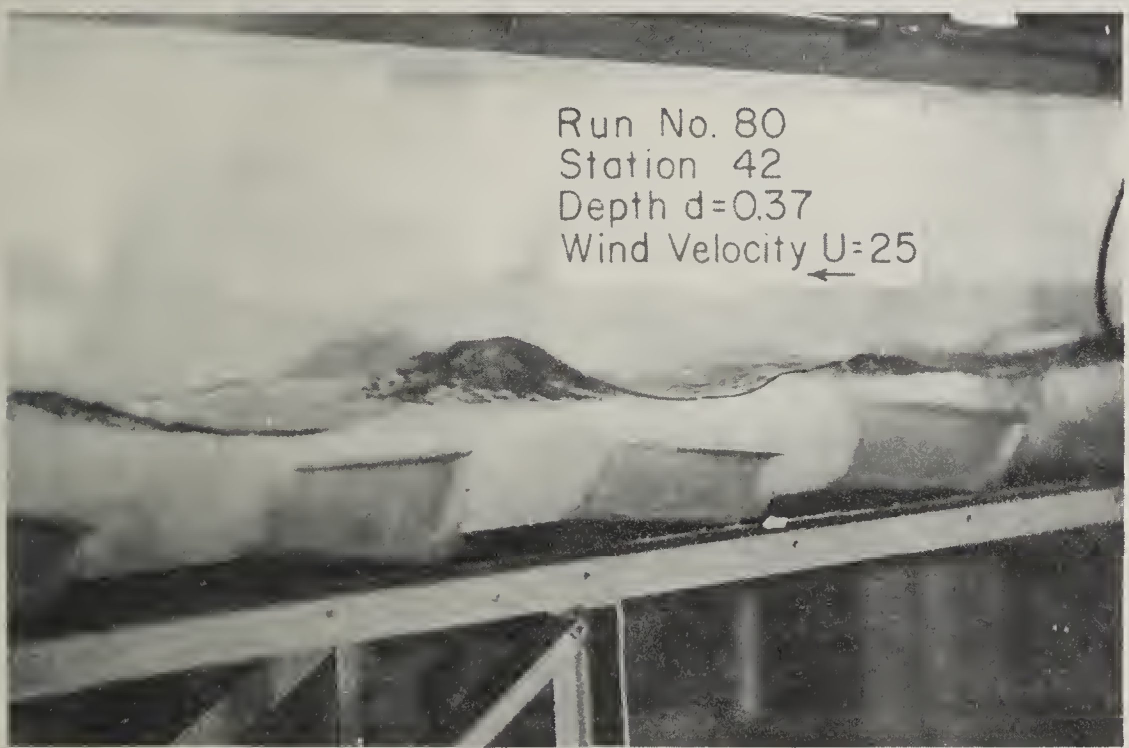


FIGURE 8 · STRIPS OF CHEESE CLOTH IN CHANNEL TO SIMULATE ROUGHNESS EFFECT OF VEGETATION

The field data from Lake Okeechobee[15] are plotted in Figure 6d and compared with the limiting curves from the smooth bottom experiments. The field data and computations are given in Table II. The scatter of the data is considerably larger than the scatter of the laboratory data, as could be expected. The trend, however, seems to be the same as indicated by the laboratory experiments. The wave heights are lower than expected for lower wind velocities, and higher than expected for higher wind velocities. This is especially pronounced for relatively shallow water. In deep water no trend with respect to the wind velocity could be established.

Summarizing the data as given in Figures 6 a to d, it may be seen that the depth starts to affect wave heights when $d_g/H_o < 5$. Disregarding the differences as already discussed above, the general trend is the same for the laboratory and the field data. The experimental curve from Figure 6a is also shown in Figure 5b as a supplement to the deep water relationship. This curve was used to correct predicted deep water wave heights for Lake Okeechobee, and these corrected heights were compared with field measurements. The wave measurements for Lake Okeechobee were obtained from Reference 15 and are summarized in Table II in this report. The percentage of error in the predictions is given in Figure 9 as a function of wind velocity, U. Most of the predictions agree with measurements within $\pm$ 50 percent. The error seems to follow, however, a definite trend. For low wind velocities the wave height predictions were usually too high (approximately 40 percent), while for high wind velocities the prediction was usually 40 or 50 percent too low. The best predictions were obtained for wind velocities between 50 and 60 ft/sec. The same trend was discovered for laboratory experiments with simulated vegetation, and was discussed above for Figure 6c.

Some of the possible reasons for the large error and scatter in data may be listed as difficulties in obtaining accurate field measurements as well as in a correct selection of wind velocities and fetches. Furthermore, the corrections were based on the depth-wave height ratio, without consideration of the depth-length ratio which should also be taken into consideration. Application of different dimensionless parameters such as gd/U^2 as recommended by Bretschneider could produce better methods of prediction.

Wave Periods in Shallow Water

The significant wave periods, $T_{1/3}$, as found from all the laboratory experiments, are plotted in Figure 10 and compared with the semi-empirical Sverdrup-Munk curve. Considering all the available laboratory and field data for deep-water, it was found desirable to shift the curve in Figure 10 slightly upward. The new curve is identical to the one determined by Bretschneider for $gF/U^2 > 100$. For lower gF/U^2 values the curve was shifted slightly upward to better fit the laboratory data approaching deep water characteristics. In the following discussions, this altered curve was used as the basis of the computation.

TABLE II

WAVE MEASUREMENTS ON LAKE OKEECHOBEE

DATE	TIME	LAKE STA.	WIND VELOCITY, U, ft./sec.	FETCH, F, miles	DEPTH AT GAGE, d_g, ft.	AVE. DEPTH across entire fetch, d_F, ft.	SIGNIF. WAVE HT., $H_{1/3}$, ft.	WAVE PERIOD, T, sec.	gF/U^2	DEEP WATER WAVE HEIGHT, H_o, ft.	DEEP WATER WAVE PERIOD, T_o, sec.	$H_{1/3}/H_o$	d_g/H_o	T/T_o	$\frac{d_g}{5.12\,T_o^2} = \frac{d_g}{L_o}$	$\frac{d_F}{5.12\,T_o^2} = \frac{d_F}{L_o}$
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1949 8-26	1900	14	60.5	23.9	10.2	11.0	3.3	4.9	1240	8.30	6.67	0.40	1.23	0.73	0.045	0.048
	2000	12	60.1	8.3	6.2	4.5	1.8	4.0	390	5.02	4.94	0.359	1.24	0.81	0.050	0.036
	2100	12	70.4	8.4	5.0	4.0	1.8	3.5	286	5.86	5.20	0.307	0.853	0.67	0.036	0.028
	2130	12	79.9	6.0	4.5	3.6	1.4	3.3	222	6.74	5.52	0.207	0.667	0.598	0.029	0.024
8-27	0200	12	91.0	25.5	12.5	10.8	4.0	5.6	576	13.26	8.09	0.301	0.942	0.692	0.037	0.032
	0300	12	73.3	22.5	11.3	11.6	2.7	5.4	870	10.36	7.30	0.260	1.090	0.740	0.041	0.042
	0400	12	60.5	20.0	10.7	12.7	2.4	5.0	1180	8.07	6.58	0.297	1.325	0.760	0.045	0.052
	0500	12	52.9	18.3	10.7	12.5	2.3	4.4	1370	6.60	5.99	0.348	1.621	0.735	0.058	0.068
	0600	12	49.1	20.0	10.7	12.4	2.3	4.2	1480	5.93	5.68	0.387	1.804	0.739	0.065	0.075
1950 10-17	1900	10	31.5	2.4	3.3	3.4	0.5	2.0	410	1.39	2.55	0.359	2.374	0.784	0.099	0.102
		14	33.0	6.3	7.7	11.4	1.2	3.0	980	2.22	3.38	0.540	3.468	0.888	0.132	0.194
	2000	10	28.6	2.4	3.4	3.6	0.5	2.0	500	1.24	2.45	0.403	2.741	0.816	0.111	0.117
		12	29.3	7.8	8.6	8.3	1.4	3.0	1540	2.14	3.44	0.654	4.018	0.872	0.142	0.136
		14	29.8	9.0	7.6	10.8	1.2	3.0	1730	2.33	3.61	0.515	3.261	0.831	0.114	0.161
		15	20.5	0.5	8.7	7.7	0.3	2.1	201	0.43	1.38	0.697	20.2	1.52	0.897	0.793
	2100	10	33.3	2.5	3.4	3.9	0.8	2.0	384	1.49	2.66	0.536	2.281	0.752	0.094	0.107
		12	33.0	7.8	8.6	8.2	1.8	3.1	920	2.16	3.32	0.833	3.981	0.934	0.152	0.145
		14	32.1	11.5	7.6	11.1	1.4	3.1	1890	2.81	3.95	0.498	2.704	0.785	0.095	0.138
		15	25.3	0.8	8.7	7.7	0.4	2.0	248	0.62	1.66	0.645	14.0	1.205	0.617	0.546
	2200	10	37.7	2.7	3.3	4.0	1.0	2.0	323	1.76	2.87	0.568	1.875	0.697	0.078	0.094
		12	34.7	7.8	8.6	8.2	1.5	3.2	1100	2.59	3.68	0.579	3.320	0.870	0.124	0.118
		14	38.0	12.8	7.6	11.0	1.7	3.4	1510	3.56	4.40	0.477	2.134	0.773	0.077	0.110
		15	24.9	0.9	8.4	7.4	0.4	2.2	245	0.68	1.74	0.588	12.4	1.26	0.542	0.477
		16	38.6	21.8	8.5	10.3	1.2	3.2	2480	4.54	5.10	0.264	1.872	0.627	0.064	0.077
	2300	10	39.6	2.7	3.5	4.2	0.9	2.1	294	1.88	2.95	0.478	1.861	0.712	0.079	0.094
		12	39.1	7.8	8.5	8.1	1.8	3.4	863	2.93	3.87	0.614	2.901	0.879	0.111	0.105
		14	39.9	13.4	7.8	11.0	2.0	3.7	1430	3.84	4.59	0.520	2.031	0.806	0.072	0.101
		15	24.9	0.9	8.5	7.5	0.5	2.5	246	0.68	1.75	0.735	12.5	1.43	0.541	0.477
		16	42.4	21.8	8.6	10.3	1.2	3.2	2060	5.04	5.28	0.238	1.706	0.606	0.060	0.072
	2400	10	49.4	2.8	3.6	4.3	1.0	2.4	194	2.42	3.24	0.413	1.49	0.74	0.067	0.080
		12	40.6	6.8	8.4	8.0	2.1	3.5	700	2.92	3.78	0.719	2.88	0.925	0.114	0.109
		14	44.0	12.8	7.9	11.1	2.8	4.2	1120	4.22	4.73	0.663	1.87	0.887	0.068	0.096
		15	38.1	1.0	8.3	7.3	1.1	3.3	116	1.17	2.19	0.940	7.09	1.506	0.337	0.296
		16	44.4	21.8	8.7	10.2	1.3	3.2	1870	5.33	5.45	0.243	1.63	0.587	0.057	0.067
		17	44.4	20.5	8.0	11.4	1.9	2.8	1760	5.21	5.38	0.364	1.54	0.520	0.053	0.076
-18	0100	10	57.9	2.9	3.8	4.4	1.5	3.2	153	3.02	3.62	0.496	1.26	0.883	0.056	0.065
		12	46.5	6.8	8.2	7.8	2.4	3.6	530	3.35	4.05	0.716	2.45	0.888	0.097	0.092
		14	44.3	13.0	8.1	10.9	3.4	4.5	1130	4.28	4.76	0.794	1.89	0.945	0.069	0.093
		15	38.1	0.9	8.1	7.1	1.0	3.3	105	1.12	2.12	0.892	7.23	1.556	0.352	0.308
		16	49.3	21.7	8.9	9.4	1.9	3.5	1510	6.03	5.74	0.315	1.48	0.609	0.052	0.055
		17	50.4	19.9	8.5	11.5	2.0	2.8	1320	5.93	5.67	0.337	1.43	0.493	0.051	0.069
	0200	10	63.8	4.0	3.9	6.8	1.4	3.8	166	3.79	4.06	0.369	1.03	0.935	0.046	0.080
		12	54.5	6.8	7.9	7.2	2.7	3.7	389	4.05	4.36	0.666	1.95	0.848	0.081	0.073
		14	57.5	13.2	8.1	11.0	3.6	4.5	675	5.76	5.37	0.625	1.41	0.837	0.054	0.074
		15	42.5	1.6	7.9	6.9	1.1	3.7	150	1.63	2.64	0.674	4.85	1.401	0.221	0.193

TABLE II (cont.)

DATE	TIME	STATION	U, ft./sec.	F, miles	d_g, ft.	d_F, ft.	$H_{1/3}$, ft.	T, sec.	gF/U^2	H_o, ft.	T_o, sec.	$H_{1/3}/H_o$	d_g/H_o	T/T_o	d_g/L_o	d_F/L_o
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1950	0200	16	57.0	22.0	9.2	9.5	2.3	4.5	1150	7.16	6.14	0.321	1.28	0.732	0.047	0.049
10-18		17	53.7	20.0	8.9	11.1	2.0	2.6	1210	6.45	5.88	0.310	1.38	0.442	0.050	0.062
	0300	10	60.7	9.0	4.1	8.9	1.9	3.2	414	5.16	4.91	0.368	0.79	0.651	0.033	0.072
		12	55.4	6.8	7.6	7.1	2.9	4.0	375	4.10	4.37	0.707	1.85	0.915	0.077	0.072
		14	62.3	15.1	8.7	10.9	3.6	4.8	660	6.65	5.78	0.541	1.31	0.830	0.050	0.063
		15	42.5	1.9	8.1	7.0	1.1	3.5	179	1.74	2.77	0.632	4.66	1.263	0.206	0.178
		16	62.6	22.1	9.3	9.2	2.5	4.7	965	7.89	6.40	0.316	1.18	0.734	0.044	0.043
		17	59.5	20.0	9.5	10.6	3.3	2.7	959	7.16	6.10	0.460	1.33	0.442	0.049	0.055
	0330	10	60.1	12.0	4.5	6.6	2.0	3.1	565	5.28	5.39	0.378	0.85	0.575	0.030	0.044
		12	67.1	6.8	7.5	7.0	3.1	4.0	256	5.03	4.78	0.616	1.49	0.836	0.064	0.059
		14	64.2	16.8	8.9	11.1	3.6	5.1	694	8.09	6.00	0.444	1.10	0.850	0.048	0.060
		15	44.0	1.9	7.5	6.5	1.1	3.5	167	1.81	2.81	0.607	4.14	1.245	0.185	0.160
		16	66.8	22.0	9.6	9.4	2.6	4.6	837	9.58	6.61	0.271	1.00	0.695	0.042	0.042
		17	63.6	20.0	9.9	10.7	3.8	2.9	840	7.68	6.04	0.494	1.29	0.480	0.052	0.057
	0400	12	68.9	6.7	7.4	6.8	2.8	4.0	240	5.16	4.84	0.542	1.43	0.826	0.061	0.056
		14	71.4	17.0	8.9	10.6	3.5	5.1	565	8.08	6.37	0.433	1.10	0.800	0.042	0.051
		15	44.0	0.6	7.3	6.2	0.7	3.2	52.8	1.09	2.07	0.642	6.70	1.545	0.333	0.283
		16	69.8	22.0	9.9	8.9	2.7	4.4	77.0	3.33	3.65	0.810	2.97	1.205	0.145	0.130
		17	67.0	20.0	10.5	11.5	4.0	3.1	75.8	3.07	3.43	1.302	3.42	0.903	0.174	0.191
	0430	10	88.0	2.8	3.5	3.8	1.4	2.7	61.0	4.82	4.27	0.290	0.73	0.632	0.037	0.040
		12	67.6	6.8	7.0	6.7	2.4	3.9	252	5.11	4.83	0.469	1.37	0.807	0.058	0.056
		14	71.8	11.5	8.6	11.5	3.1	5.0	378	6.88	5.69	0.450	1.25	0.878	0.051	0.069
		15	44.0	0.5	6.8	5.8	0.6	2.7	44.0	1.03	1.99	0.582	6.60	1.356	0.334	0.285
		16	74.3	22.2	9.8	9.0	2.7	4.2	690	9.61	6.93	0.280	1.02	0.606	0.039	0.036
		17	72.7	20.0	10.9	11.5	3.0	3.2	643	8.87	6.67	0.338	1.23	0.479	0.047	0.050
	0500	10	88.0	2.8	3.4	3.3	1.2	2.3	62.0	4.82	4.27	0.248	0.70	0.538	0.036	0.035
		12	66.0	6.8	7.5	6.8	2.2	3.9	265	5.01	4.76	0.439	1.50	0.819	0.064	0.058
		16	76.1	22.0	9.8	9.1	2.7	4.1	651	9.88	6.99	0.273	0.99	0.586	0.039	0.036
	0900	10	46.3	6.0	2.5	1.0	0.5	2.3	475	3.20	3.90	0.156	0.78	0.589	0.032	0.012
		14	51.2	7.4	6.8	5.2	0.8	2.8	480	3.91	4.31	0.204	1.74	0.649	0.071	0.054
		15	39.6	0.8	8.9	7.9	1.9	3.8	87.0	1.12	2.10	1.696	7.95	1.809	0.393	0.349
		17	40.6	3.8	5.6	2.7	0.9	2.4	390	2.25	3.26	0.400	2.49	0.736	0.102	0.049
	1000	10	64.8	6.0	2.2	1.0	0.7	2.5	243	4.69	4.54	0.149	0.47	0.550	0.020	0.009
		14	51.3	7.9	6.7	5.0	0.9	2.9	510	4.00	4.42	0.225	1.68	0.656	0.067	0.050
		15	31.5	1.7	8.7	7.7	1.8	3.8	293	1.17	2.34	1.538	7.44	1.623	0.309	0.274
		17	45.0	3.8	5.4	2.2	1.2	2.5	320	2.52	3.43	0.476	2.40	0.728	0.089	0.036
	1100	14	66.0	6.3	7.0	5.1	0.9	2.8	246	4.87	4.65	0.184	1.44	0.602	0.063	0.046
		15	38.1	0.9	9.4	8.4	1.4	3.8	105	1.12	2.12	1.250	8.39	1.792	0.408	0.365
		17	45.4	3.8	5.4	1.9	0.8	2.7	304	2.50	3.40	0.320	2.16	0.794	0.091	0.032
	1200	14	49.8	7.3	7.2	5.2	0.9	2.6	500	3.78	4.26	0.238	1.90	0.610	0.077	0.055
		15	27.9	0.8	9.3	8.5	1.2	3.7	175	0.75	1.80	1.600	12.4	2.055	0.560	0.512
		17	33.7	3.8	5.7	2.0	1.1	2.7	570	1.73	3.01	0.635	3.29	0.897	0.122	0.043
	1300	14	34.5	7.7	7.3	5.5	0.8	2.7	1110	2.58	3.66	0.310	2.83	0.737	0.106	0.080
		15	19.0	0.8	9.2	8.4	1.0	3.5	375	0.48	1.50	2.083	19.2	2.333	0.800	0.730
		17	33.3	3.8	6.1	2.4	1.2	2.6	585	1.78	2.97	0.674	3.43	0.875	0.134	0.053
	1400	14	33.0	7.6	7.5	5.7	0.6	2.6	1190	2.45	3.60	0.244	3.06	0.722	0.112	0.085
		15	24.9	1.5	9.3	8.3	0.9	3.3	408	0.86	2.00	1.046	10.8	1.650	0.453	0.404
		17	33.4	3.8	6.6	2.8	0.9	2.6	577	1.80	2.98	0.500	3.67	0.872	0.145	0.061

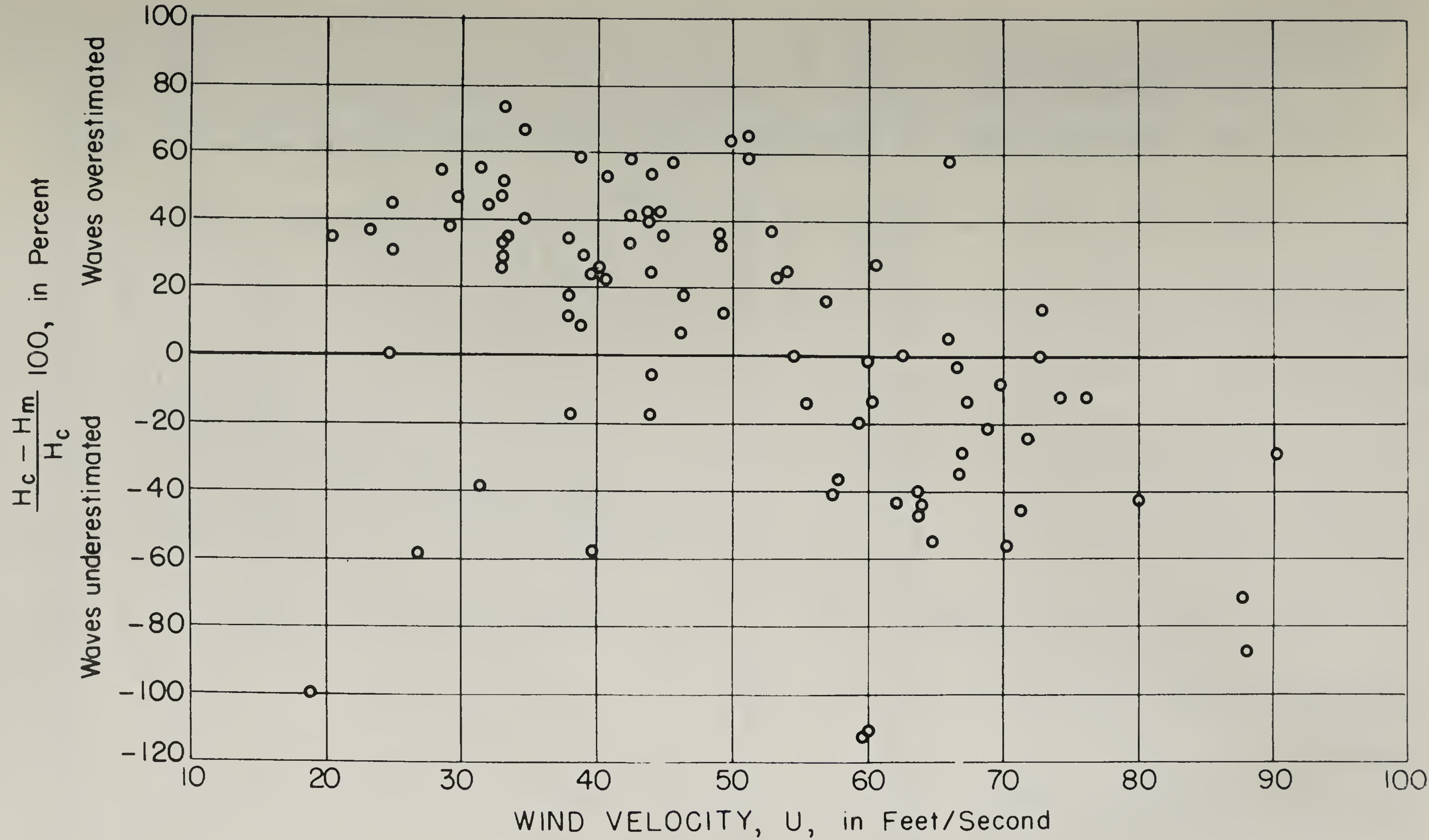


FIGURE 9 PERCENTAGE ERROR IN PREDICTING SHALLOW WATER WAVES AS A FUNCTION OF WIND VELOCITY FOR LAKE OKEECHOBEE

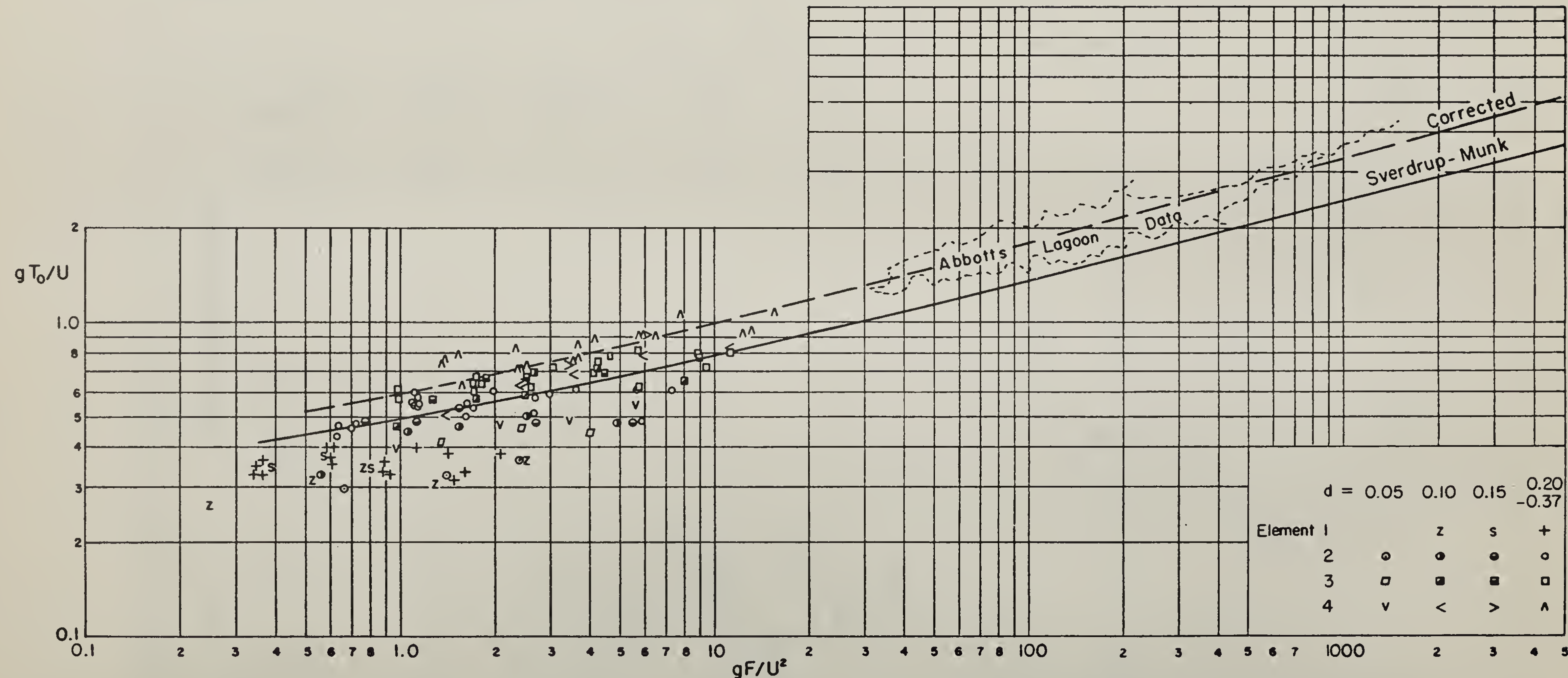


FIGURE 10 · DEEP WATER WAVE PERIOD AS A FUNCTION OF WIND INTENSITY AND FETCH

There is a definite trend for shorter periods in shallower water. The bottom effect on wave periods is not so pronounced as it was on wave heights. The changes in wave periods were plotted as a function of d_g/L_o, where d_g was again the depth of water at the point of measurements, and L_o the deep-water wave length: $L_o = 5.12 T_o^2$, where T_o is the deep-water wave period and could be predicted from the known fetch and wind velocity. All the laboratory experiments indicate the same trend for both the smooth and rough bottom and with the simulated vegetation. The smooth-bottom results were used again to obtain the empirical relationship between the wave periods and the depth of water. Figure 11a demonstrates that 90 percent of the results were within $\pm$ 20 percent error limits from an average curve, and 65 percent were within $\pm$ 10 percent error limits. These curves from Figure 11a were transferred to Figure 11 b, c, d and e. The field measurements indicate the same trend for the region of d_g/L_o between 0.2 and 0.07. The range $d_g/L_o < 0.06$ was not covered by the laboratory experiments.

The laboratory experiments demonstrate further that with $d_g/L_o > .2$ the depth of water does not have any influence on wave period and the deep-water curves can be used.

Wave Statistics

For design purposes it is important to predict the maximum wave heights and periods when the mean or significant wave heights and periods are known. The relationships between the mean, significant, and maximum wave heights are shown in Figure 12 a to c. All the experimental points give a straight-line relationship. The scatter is very small ($\pm$ 10 percent) when the mean and significant values were concerned. The maximum value represents only one measurement out of every 100 waves and so the scatter is expected to be larger. The $\pm$ 20 percent scatter for these points may be considered as a very good result. The maximum wave height was found to be 1.34 times the significant wave height, which is exactly the same value as determined by the Jacksonville District, Corps of Engineers, for Lake Okeechobee(14) and slightly smaller than the 1.37 as given by Saville(15) for the same lake. The ratio between the maximum and significant wave heights for the ocean was determined by Putz(16) to be 1.81. The measurements made by Wiegel(17) for ocean waves along the Pacific Coast gave a value of 1.87 $\pm$ 20 percent for this ratio. It should be noted that the Putz and Wiegel results concern only deep-water waves in the ocean. In shallow water the wave heights are also controlled by the water depth and so the shallower the water the more uniform probably would be the wave heights. Within the limits of this experiment, no different ratios for various depths could be obtained. The results were also the same for different lengths of fetch (except very short fetches which are not included in the data).

Statistical data for wave periods in shallow-water are shown in Figure 13a to c for individual wave periods; in Figure 14 for the periods of

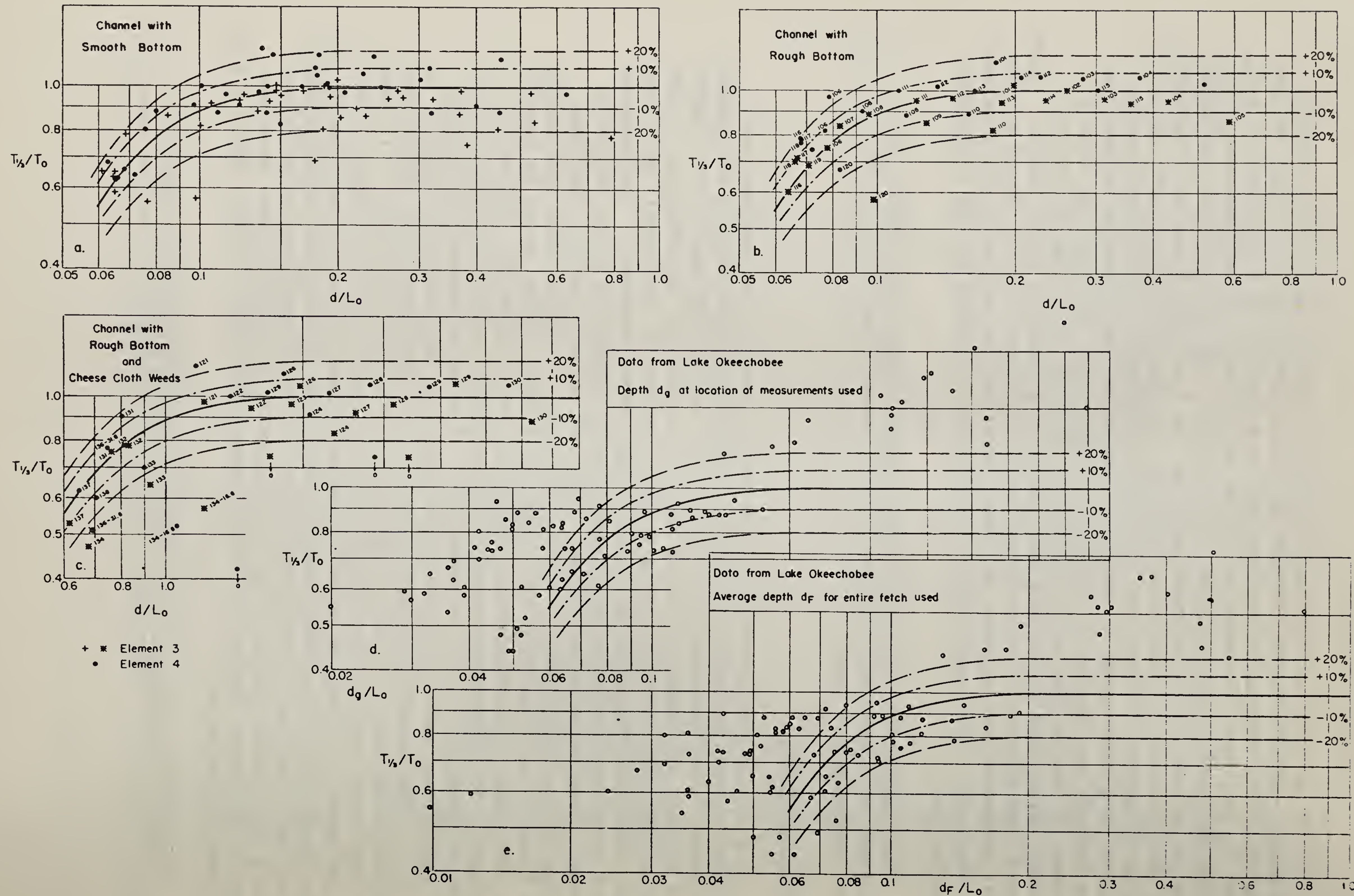


FIGURE 11 · WAVE PERIOD AS A FUNCTION OF DEPTH

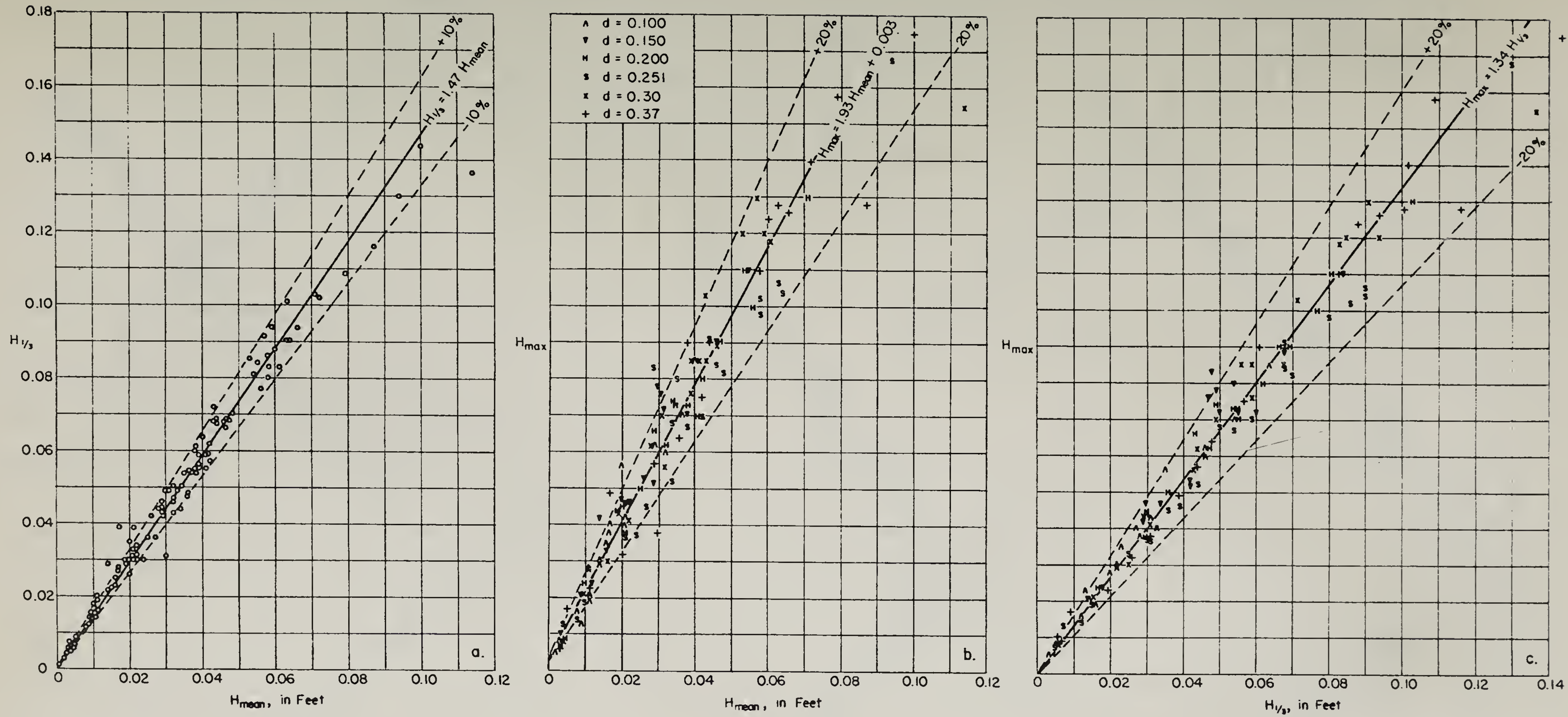


FIGURE 12 · RELATIONSHIP BETWEEN MEAN, SIGNIFICANT AND MAXIMUM WAVE HEIGHTS

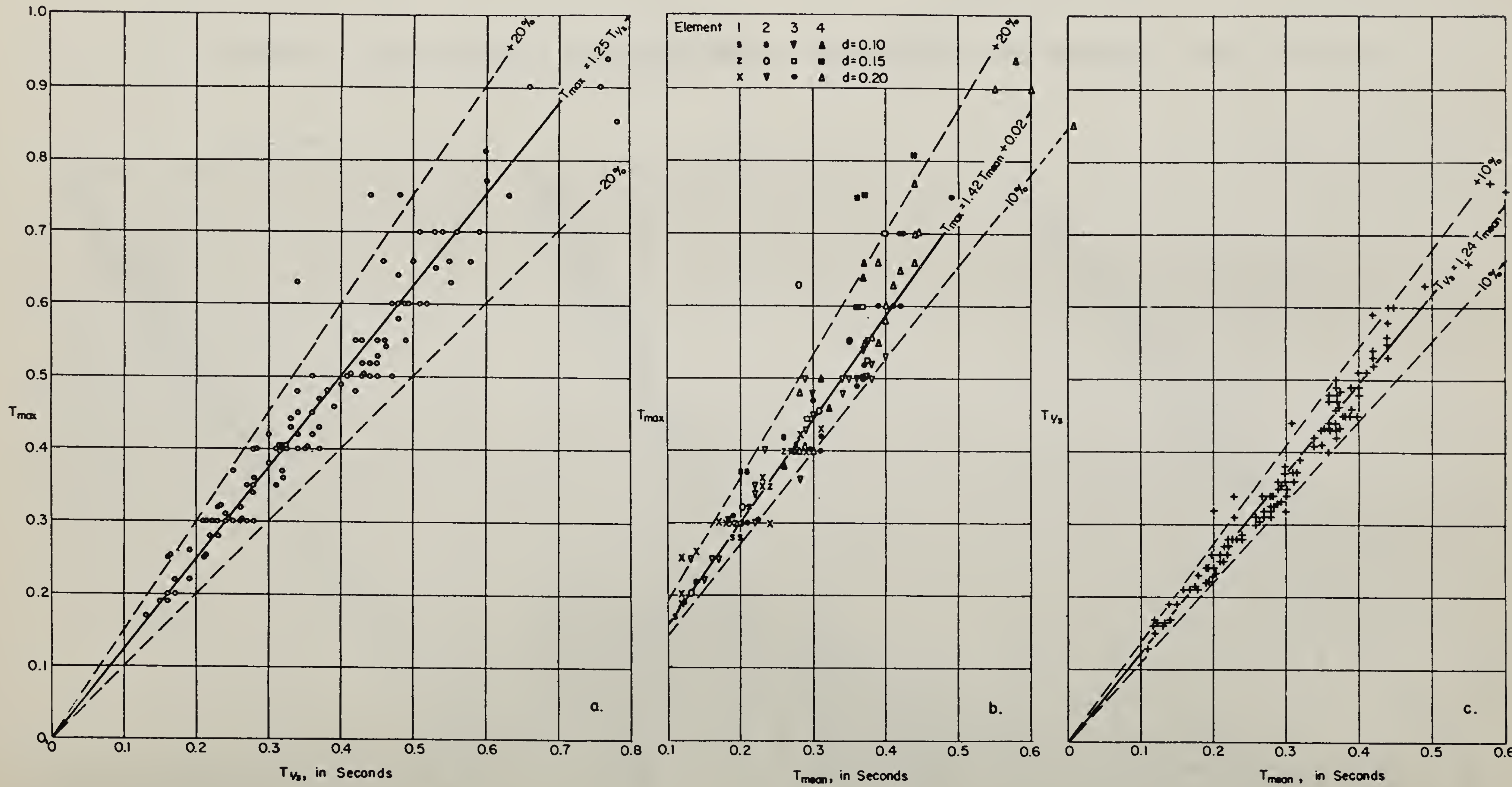


FIGURE 13 · RELATIONSHIP BETWEEN MEAN, SIGNIFICANT AND MAXIMUM WAVE PERIODS

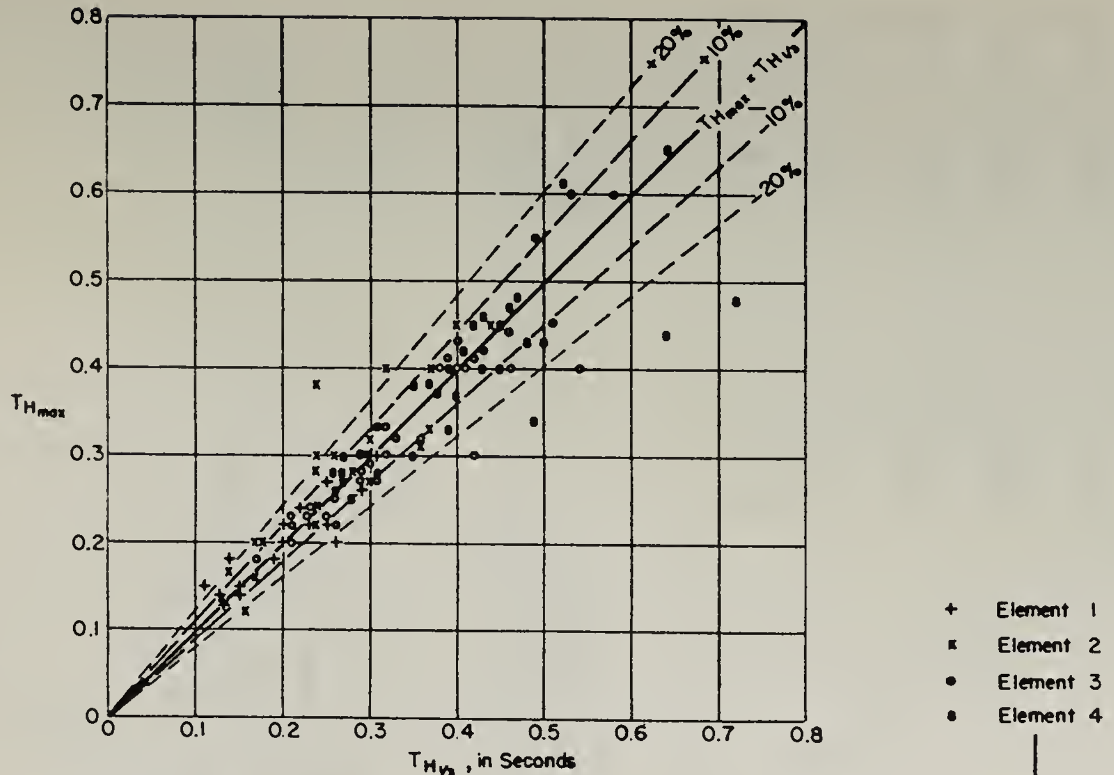
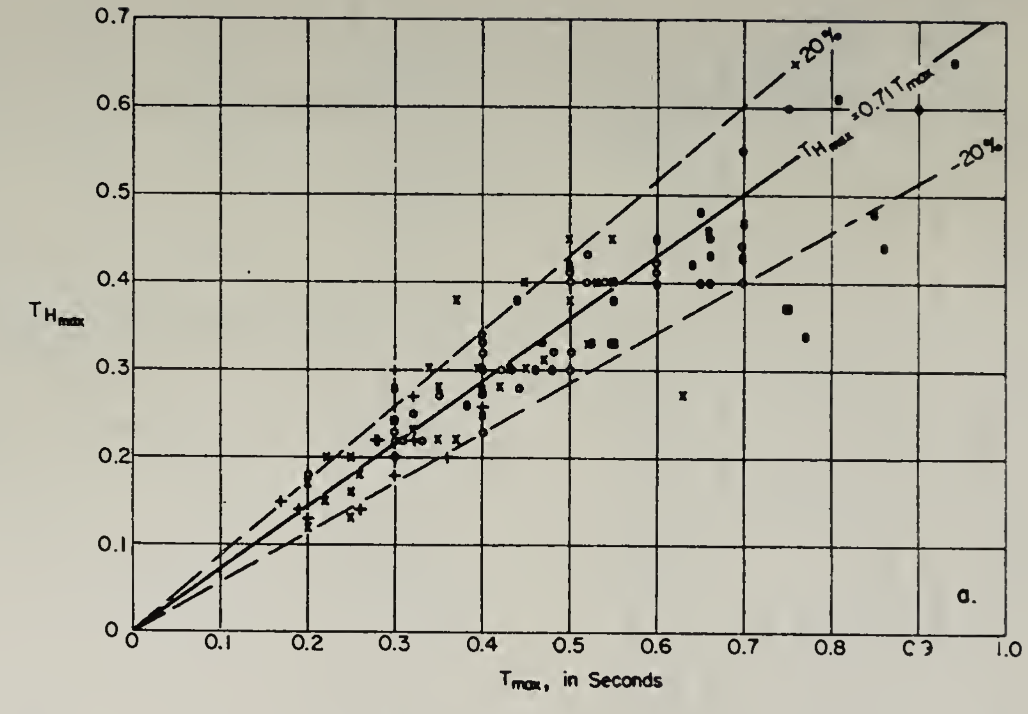
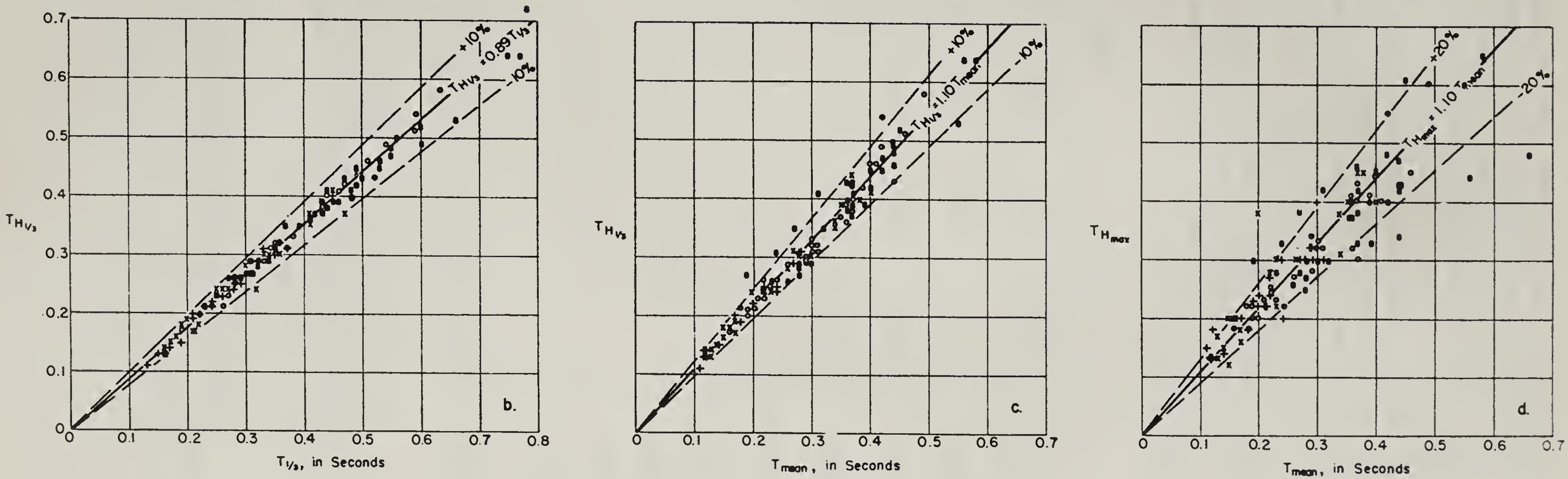


FIGURE 14
RELATIONSHIP BETWEEN PERIOD OF SIGNIFICANT WAVE HEIGHT AND THAT OF MAXIMUM WAVE HEIGHT





RELATIONSHIP BETWEEN INDIVIDUAL WAVE PERIODS AND WAVE PERIODS OF MEAN, SIGNIFICANT AND MAXIMUM WAVE HEIGHTS
FIGURE 15

significant and maximum wave heights; while in Figure 15a to d the individual wave periods are compared with the periods of the mean, significant, and maximum wave heights. The data are unique for all cases, and no variation could be found for various water depths and lengths of fetch. The scatter, as expected, was large ($\pm$ 20 percent) for maximum values, and very small ($\pm$ 10 percent) where the significant and mean values were concerned. It is interesting to note that the maximum wave period never coincided with the maximum wave height, and that the period of the wave of maximum height and the average period of the significant wave heights were of the same value and equal to 1.10 times the mean wave period, T_{mean}. Hence, the periods of the maximum and significant wave heights could be derived through the simple observation of the mean wave periods. The complete results are given in Table III.

TABLE III

a \ b	H_{mean}	$H_{1/3}$	H_{max}	$T_{H_{mean}}$	$T_{H_{1/3}}$	$T_{H_{max}}$	T_{mean}	$T_{1/3}$	T_{max}
H_{mean}	1.00	0.68	0.52	-	-	-	-	-	-
$H_{1/3}$	1.47	1.00	0.75	-	-	-	-	-	-
H_{max}	1.93	1.34	1.00	-	-	-	-	-	-
$T_{H_{mean}}$	-	-	-	1.00	-	-	-	-	-
$T_{H_{1/3}}$	-	-	-	-	1.00	1.00	1.10	0.89	0.71
$T_{H_{max}}$	-	-	-	-	1.00	1.00	1.10	0.89	0.71
T_{mean}	-	-	--	-	0.91	0.91	1.00	0.81	0.70
$T_{1/3}$	-	-	-	-	1.12	1.12	1.24	1.00	0.80
T_{max}	-	-	-	-	1.41	1.41	1.42	1.25	1.00

Numbers indicate the ratio a/b

The statistical distributions of wave heights are given in Figure 16. This figure demonstrates that 45 percent of the waves are smaller than the mean wave height and approximately 90 percent are smaller than the significant wave height.

The wave heights and periods were plotted for individual waves in Figure 17 a to c. The plots were made in three different groups: (a) for depths of water 0.30 to 0.37 foot; (b) for depths 0.100 to 0.150 foot; (c) for depths 0.055 to 0.085 foot. The wave steepnesses are also

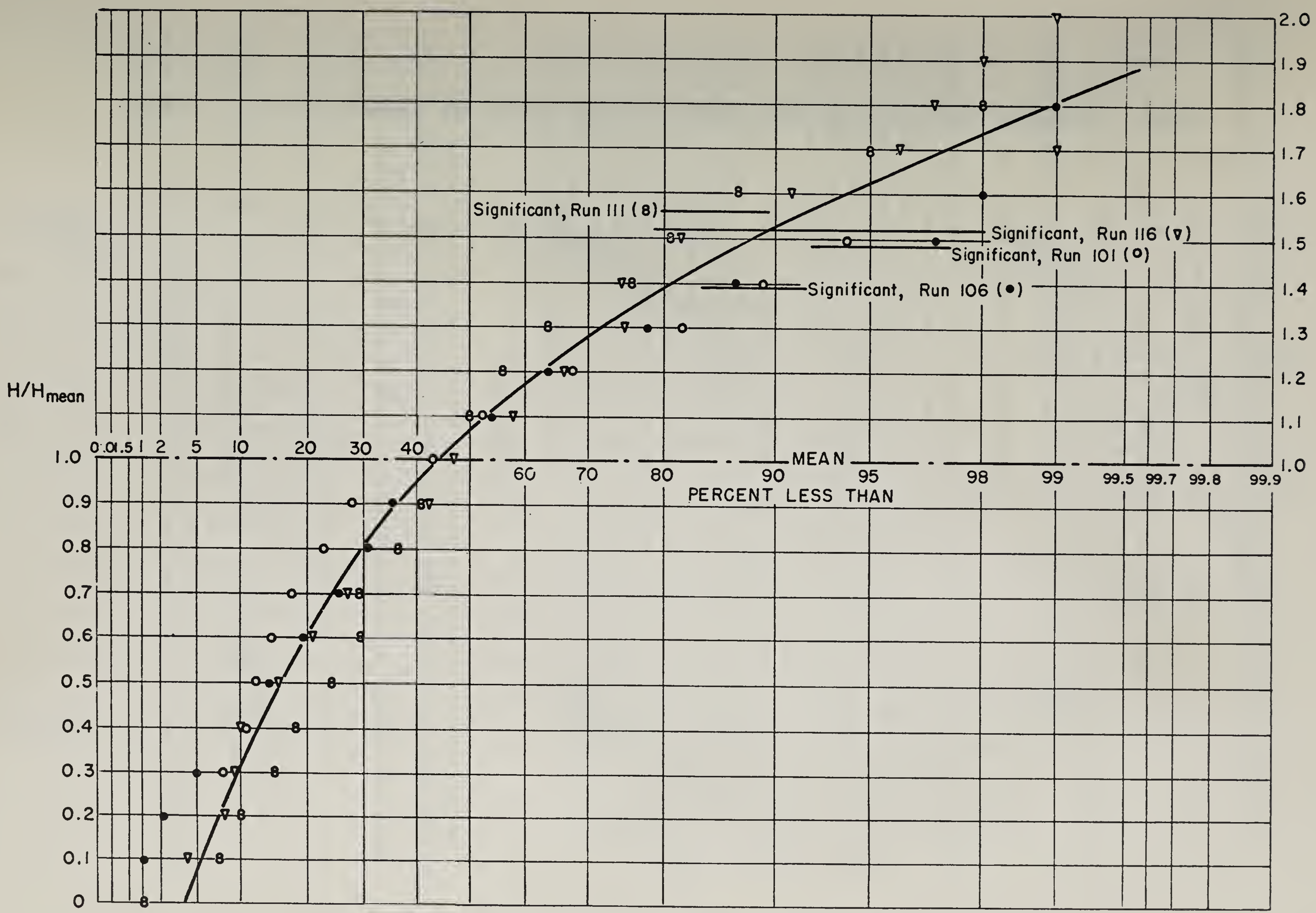


FIGURE 16 · STATISTICAL DISTRIBUTION OF WAVE HEIGHTS

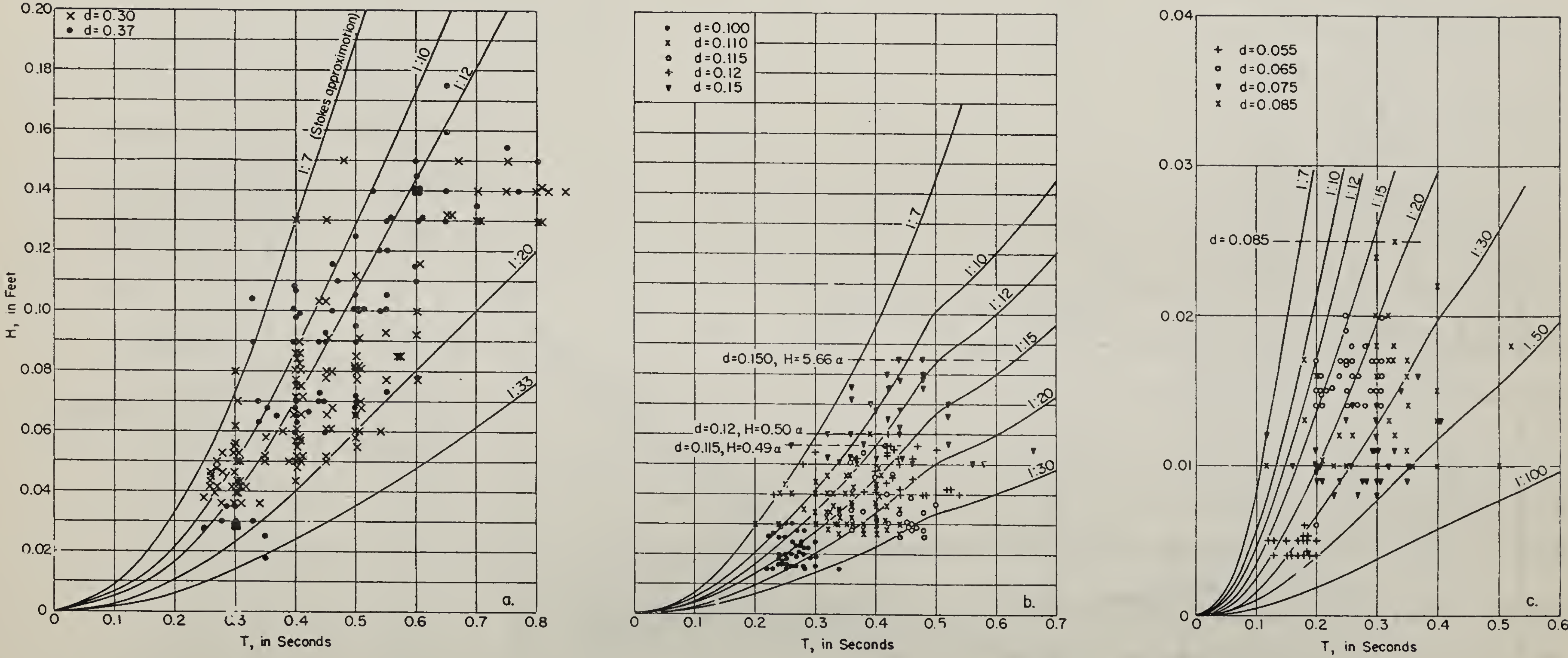


FIGURE 17 · RELATIONSHIP BETWEEN WAVE HEIGHTS AND PERIODS FOR INDIVIDUAL WAVES

indicated for each plot. The lines of equal wave steepness could be computed using the Stokes' first approximation:

$$L = 5.12\ T^2 \tanh \frac{2\pi d}{L} \qquad (7)$$

The wave steepness is given by definition as H/L, hence:

$$H = (H/L)\ L. \qquad (8)$$

Substituting Equation (8) into Equation (7) we have:

$$H = 5.12\ (H/L)\ T^2 \tanh 2\pi d/L. \qquad (9)$$

Using H/L as parameter, the curves can be plotted for the given depth d. The breaks in the computed curves in Figure 17 b and c resulted from the effect of depth variations in the last term of Equation (9). Corrections were also applied to the curves considering the increase in wave velocities when the wave steepness is increasing, or when the wave approaches the characteristics of a solitary wave in shallow water (Reference 18, Figure 14).

Figure 17 a to c demonstrates the decrease in wave steepness as the depth decreases. For the depth 0.30 to 0.37 foot, the average wave steepness is approximately 1:13; for d = 0.100 to 0.150 foot, 1:15; and for very shallow water d = 0.055 to 0.085 the average steepness is only 1:30. This demonstrates again that in deep-water the wave heights are controlled by the maximum wave steepness, while in shallow water the bottom contributes considerably in making the waves break before they reach the maximum steepness that is possible in deep water. For very shallow water, it is expected that the waves will approach the characteristics of the solitary wave.

CONCLUSIONS

The data indicate that Sverdrup-Munk-Bretschneider curves may be used to predict the wave heights and periods for relatively deep water.

The experiments indicate that the depth starts to reduce the wave heights at approximately $d/H_o < 5$.

The wave periods are reduced when $d/L_o < 0.2$.

The maximum wave height was found to be 1.34 times that of the significant wave height and 1.93 times that of mean wave height.

The average periods of the significant waves and of the maximum waves were found to be of the same magnitude and equal to 1.10 times the mean wave period.

The maximum wave period almost never coincided with the maximum wave height, and was found to be 1.25 times that of significant wave period and 1.42 times that of mean wave period.

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